THE JOURNAL

OF

"The Royal Aeronautical Society"

with which is incorporated "The Institution of Aeronautical Engineers"

Edited for the Council by Captain J. LAURENCE PRITCHARD, Hon. Fellow

No. 216. DECEMBER, 1928. Vol. XXXII.

NOTICES

Wright Anniversary Dinner

On December 17th, 1903, twenty-five years ago, Mr. Orville Wright made the first flight in the history of the world in a power-driven heavier-than-air machine. On the same day two flights were made by Mr. Wilbur Wright. To quote their own words: "The first flight lasted only 12 seconds, a flight very modest compared with that of birds, but it was, nevertheless, the first in the history of the world in which a machine carrying a man had raised itself by its own power into the air in free flight, had sailed forward on a level course without reduction of speed, and had finally landed without being wrecked. The second and third flights were a little longer, and the fourth lasted 59 seconds, covering a distance of 852 feet over the ground against a 20-mile wind."

The Science Museum at South Kensington has been entrusted with the care of the original Wright machine in which these historic first flights were made. The Council of the Royal Aeronautical Society desire not only to honour the names of Wilbur and Orville Wright, but to mark their appreciation of the trust shown by their Honorary Life Member, Mr. Orville Wright, by holding a dinner on Monday, December 17th, in the Science Museum. The tables for the dinner will be arranged around the Wright machine. Colonel Sir Henry Lyons, Director of the Science Museum, has kindly given his permission for the function, and is aiding the Society in every possible way.

The chair will be taken by the President, Colonel the Master of Sempill, A.F.C., who will also present on this occasion the various prizes and awards made by the Council during the past year.

A short address on the early work of the Wright Brothers will be given by Mr. Griffith Brewer, a Member of Council.

Members are specially asked to make early application for tickets, as there is no possibility of arranging for an overflow, and it is desirable to provide places for members before including members' friends.

The names are required for the printed list and to facilitate seating arrangements.

No tickets will be forwarded, or places reserved, unless a remittance is enclosed.

Tickets £1 10s. 0d., inclusive of wines.

International Aeronautical Exhibition, Berlin

In the last issue of the Journal an account was given of the way the Royal Aeronautical Society was represented at the Berlin International Aeronautical Exhibition held on October 7-21. Now that the results of the exhibition are becoming known, the Council wish further to place on record their thanks for the energetic services of Herr Siemens, who looked after the Society's exhibit

and explained it to visitors; to Mr. Claude Taylor, of the Department of Overseas Trade, whose unrivalled knowledge of exhibitions was placed freely at the disposal of the Society; and to Major Villiers, of the Civil Aviation Department, who gave invaluable help, in addition to those whose help was acknowledged in the November Journal.

Council Meeting

A meeting of Council was held on Tuesday, 20th November, 1928. Among the business transacted was the appointment of additional delegates to the International Civil Aeronautics Conference at Washington; the receipt of a report on the arrangements for the dinner at the Science Museum on December 17th; a consideration of the conditions of award of the Akroyd Stuart Premium; the award of the Simms Gold Medal and Taylor Medal; the election of members; the participation of the Society in the World Engineering Congress in Tokyo; the lecture programme for the second half of the Session; and provisional arrangements for an Informal Discussion in January.

International Civil Aeronautics Conference, Washington

The following additional delegates have been invited to represent the Society at the International Civil Aeronautics Conference to be held at Washington on December 12th, 13th and 14th:—Captain F. S. Barnwell, F.R.Ae.S., and Dr. J. C. Hunsaker, Hon. F.R.Ae.S.

A paper has been prepared for the Conference dealing with the following British pioneer flights:—

The First Non-Stop Trans-Atlantic Aeroplane Flight, June 14/15, 1919.
England to Australia Flight, 1919.
Flight Round Australia, 1914.
London to Australia and Return, 1926.
London to Cape Town and Return, 1925-26.
Survey Flight Round Africa, 1927-28.
Light Aeroplane Flight to Australia, 1928.

Election of Members

The following recommendations of the Grading Committee were approved by the Council at their meeting on November 20th, 1928:—

Fellow.—Frederick Alexander Lindemann.

Associate Fellows.—Alfred Charles Barlow, Alexander Cowden Carr (transferred from Student membership), Victor Montague Falkner.

Associates.—Frederick C. Bray, Fred Cook, Alfred Guy Roland Garrod, Neilson John Hancock (transferred from Student membership), John Mathew Hampden Hoare, Charles Frederick Hobart, Thomas Seth Lofthouse (transferred from Student membership), Henry Leonard Pearce, Frederic George Ping.

Students.—Frederick Charles Cooper, Ernest France, George Alan Harvey, Benjamin Robert Hodgson, Hugh Donald McKenna, George Edward Phillips, Leslie Francis Russell, Erroll Anthony Samuel-Camps, James Stuart Thomson, Henry Wood.

Companions.—Jan Carl Clason (transferred from Student grade), Edward V. Dolby (transferred from Student grade), Charles W. Miller (transferred from Student grade).

Index

With this issue of the Journal appears the annual index and title page. The arrangement adopted last year following that used for the Consolidated Subject Index has been continued. The attention of members is drawn to the Consolidated Subject Index. It is a full index of all the matter which has appeared in the Journal from 1897-1926, arranged under subjects and copiously cross-indexed. The index may be obtained from the Society's Offices, price 2s. 6d.

Students' Section

The inaugural lecture before the Students' Section was given by Major A. R. Low on Friday, November 23rd, in the Library of the Society. Major Low chose as his subject "Some New Points of View on Fluid Motion," and the chair was taken by Mr. R. Scott-Hall, Associate Fellow.

Lecture Programme—Second Half of Session, 1929

A Programme of the Lectures, arranged for the second half of the Session, will be forwarded to members by post shortly.

Branch Notes

The following lectures have been arranged before the Halton Branch:—

December 12th.—Mr. Yeatman on the Autogyro.
January 24th, 1929.—Mr. Handley Page on Slotted Wings.
February 18th, 1929.—A member of the Branch on the H.A.C.3.

Forthcoming Arrangements

December 5th.—Lecture before the Yeovil Branch by T. Dickinson, Esq., on "Evolution, Care and Maintenance of Engineers' Small Tools."
December 6th.—Lecture at the Royal Society of Arts, at 6.30 p.m., by Squadron Leader B. Hinkler, A.F.C., on "Flying to Australia."
December 12th.—Lecture before the Halton Branch by — Yeatman, Esq., on the "Autogyro."

The Chartered Institute of Patent Agents

The following letter has been received from the Chartered Institute of Patent Agents:—"I have pleasure in informing you that my Council, under Rule 3 of the Register of Patent Agents' Rules, 1920, have now considered as 'worthy of mention in the Register' the qualifications Member and Associate Member of the Royal Aeronautical Society."

PROCEEDINGS

NINTH MEETING, SECOND HALF, 63RD SESSION

At a meeting of the Royal Aeronautical Society, held in the rooms of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, April 26th, 1928, a paper on "Flying Boats," by Dr. C. Dornier, was read and discussed. Colonel the Master of Sempill (President of the Society) in the chair.

The CHAIRMAN: Members of the Society would be specially glad to welcome Dr. Dornier, coming, as he did, so soon after the magnificent East to West flight of the "Bremen" across the North Atlantic. The Society was very much indebted to Major Low, of the Air Ministry, for having translated Dr. Dornier's paper, and would also be indebted to Mr. Bramson, who was going to read the paper. As a matter of fact, Dr. Dornier's English was very good, but he was such a modest man that he had considered it would be easier for the audience if the paper were read by Mr. Bramson.

Dr. Dornier was educated at Munich, where he had taken an engineering degree. Until 1910 he was employed on civil engineering work, mainly relating to the design and construction of bridges. In 1910 he went to Friedrichshafen and joined the staff of Count Zeppelin, and from that time until 1914 he was employed exclusively in the design of rigid airships. In 1914, at Count Zeppelin's request, he transferred his activities entirely to heavier-than-air craft, and had been engaged on that work ever since. Count Zeppelin was a firm believer in the large flying boat, and was continually pressing Dr. Dornier to produce designs. Dr. Dornier's flying boats were famous for the magnificent flights they had made, and also for the fact that they were in service regularly on many air transport lines. The Dornier Wal had made two successful flights across the South Atlantic, and the wonderful flight of Captain Amundsen to the Arctic, as well as many other flights which were too well known to need retailing. Dornier flying boats held, at the moment, 13 of the international records approved by the F.A.I. Dr. Dornier constructed a number of factories —two in Italy, one in Switzerland, one in Holland and one in Germany—and employed in all some 3,000 men on flying boat construction. In his Italian factories he had constructed to date over 100 machines of the Dornier Wal type, and there were 40 machines of that type now on order. In the Dutch factory he had constructed six machines of the Wal type; these had been delivered, and it was hoped that another nine would be delivered this year. In Germany 12 super-Wal had already been made and seven more were building. In the Swiss factory there were under construction three giant machines of 6,000 h.p., which would have a total loaded weight of from 45 to 50 tons. Dr. Dornier was uniquely qualified to present a paper on flying boats.

NOTES ON A FAMILY OF SIMILAR FLYING BOATS

BY C. DORNIER.

The importance of the flying boat was first generally recognised in England, and no other country can look back on so long continuous and systematic development of building flying boats. For this reason I feel it a special distinction that the Royal Aeronautical Society has asked me to give a lecture here, and I meet their wishes with pleasure.

It was not so easy to select material from a subject so wide and so rich in problems, and this finally decided me to make the fruits of authentic experience available to you in a composite form. The material can be appreciated only in a comparative sense, but should, none the less, be of general interest.

So much has been theorised about the influence of increasing dimensions on the performance of aeroplanes, that it is not without interest to treat the subject for once from the point of present practice.

I shall present to you the data of construction and performance of a family of four flying boats of widely different sizes, all thoroughly tried and tested.

The data have been most conscientiously assembled. The weights are mean values of a large number of completed machines. The flying performances are likewise means of performances actually achieved.

To make the comparison as clear as possible all the selected flying boats were fitted with air-cooled engines and as little different as possible in type of construction, which was all-metal except for part of the covering of the wing, tail control and aileron surfaces.

All have stump wings introduced by me ten years ago and are all of semi-cantilever high wing construction. The engines are installed above the wings and in multi-engine boats are in tandem. The hulls are of duralumin, and the spars and highly stressed parts are of high-tensile steel by deliberate preference.

To give a glimpse into the near future, I include, in the diagrams and tables, the *calculated* data of construction and performance of a large flying boat, which will be completed in a few months. It will also be equipped with air-cooled engines, and sufficient accuracy may be claimed for the weights, which are largely obtained from measurement of completed parts.

Table I. gives the principal comparative data of five types.

TABLE I.

Type.	Engine.	H.P.	Total lifting surface m²	Span in m.	Length in m.	Airscrew clearance above w.l. in m.	
A	Siemens	1 of 80	15.5	9.8	7.477	0.72	Libelle
B	Gnome-Rhone Jupiter	1 ,, 450	52.9	17.5	12.855	1.40	Do E
C	,,	2 ,, 450	95.2	22.5	17.575	1.81	Wal
D	,,	4 ,, 500	143.8	28.6	24.600	2.24	Superwal
E	,,	12 ,, 500	467.7		40.050	6.45	Do X

I shall give first a brief general description of the flying boats under comparison, with reference to their common points and to the unavoidable differences to be noted.

In the first place, though all are equipped with air-cooled engines, sensible constructional and aerodynamical differences exist which must be kept in mind.

A is a flying boat with an 80 h.p. Siemens-Halske engine, weighing about 140 kg., or 1.75 kg./h.p.

In Fig. 1 the flying boats are shown in plan-silhouette, on the same scale.

Figs. 2 and 3 give front and side views of flying boat A, named the "Libelle" (Dragonfly), with folding back wings, the point of greatest difference, since none of the others have folding wings.

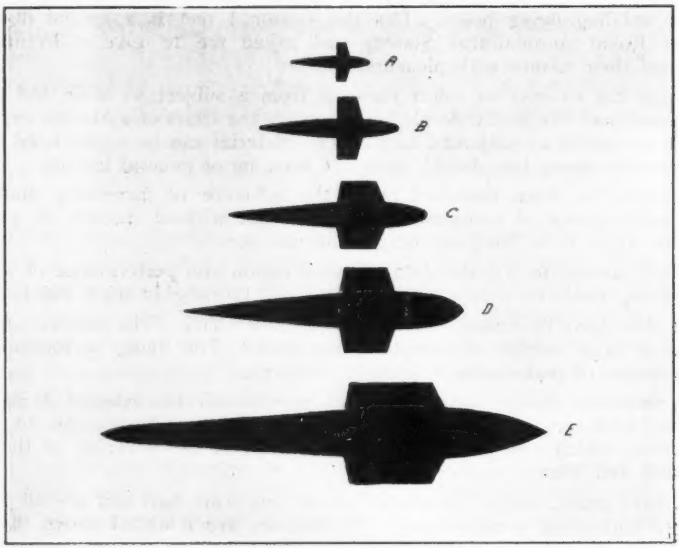

FIG. 1.

FIG. 2.

B and C have both 450 h.p. Jupiter engines, Series IV. weighing 330 kg., or only .74 kg./h.p.

A has a tractor airscrew, B a propeller airscrew.

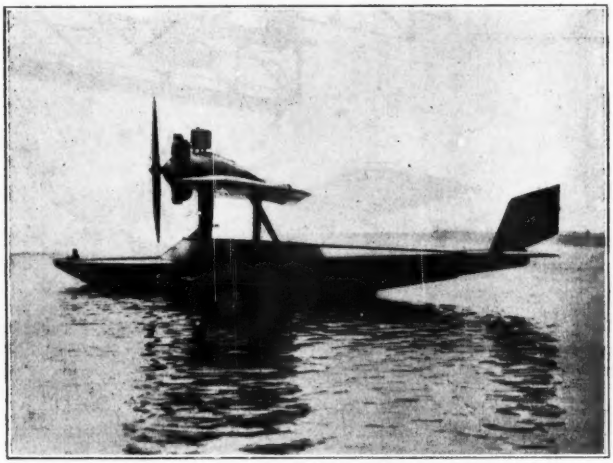

FIG. 3.

FIG. 4.

D and E are equipped with 500 h.p. Jupiter VI. engnes, weighing 395 kg., or 0.79 kg./h.p., practically the same wgt/h.p. as the engines of B and C, but the slower running airscrews giving more favourable aerodynamical conditions.

Figs. 4 and 5 give a front and side view of B type which has a pronounced

similarity with the smaller A type, but with larger dimensions, and without folding wings.

The engines are installed differently. The engine cradle of A is built into

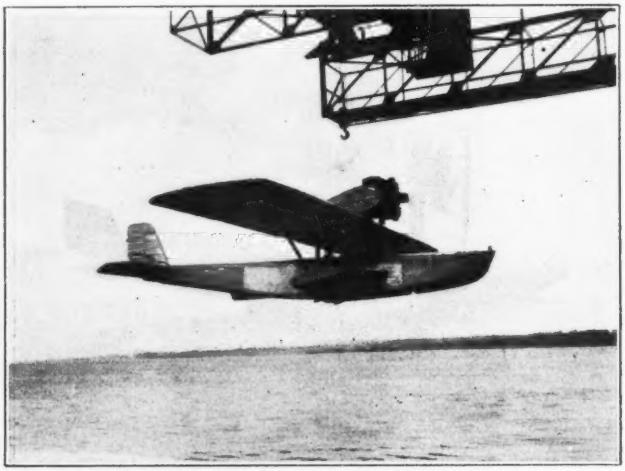

FIG. 5.

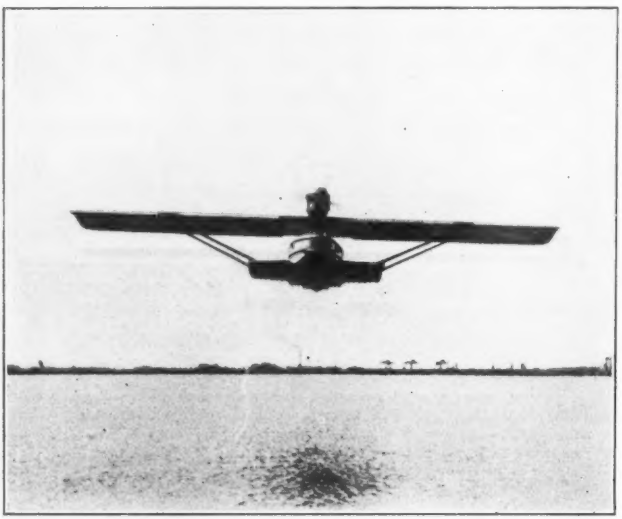

FIG. 6.

the wing structure, while that of B is fastened at three points and is quickly detachable. Type C is generally known as the "Dornier-Wal," and is shown in the next two illustrations, with marked general similarity of form, but distinguished by the installation of two engines in tandem.

The next three illustrations show different views of type D, known as the "Super-Wal," which established twelve international records in the beginning of this year.

The family resemblance with the others is evident. The distinctive feature is the installation of four engines, two pairs in tandem. The engine cradles are

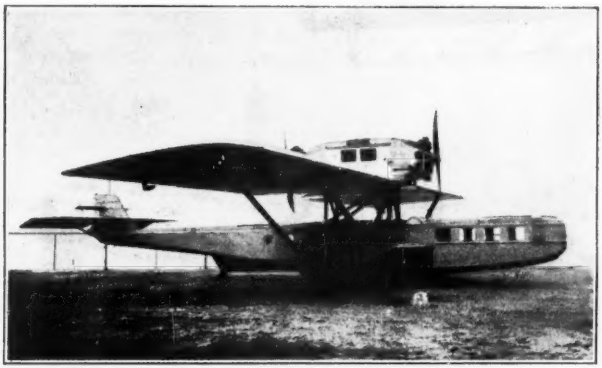

FIG. 7.

very similar internally to that of type C, but the engine housing is built into the structure of C, while the housings of D are attached by a small number of bolts and are easily detachable.

There are as yet no available photographs of type E, which is a further and higher development of the previous types.

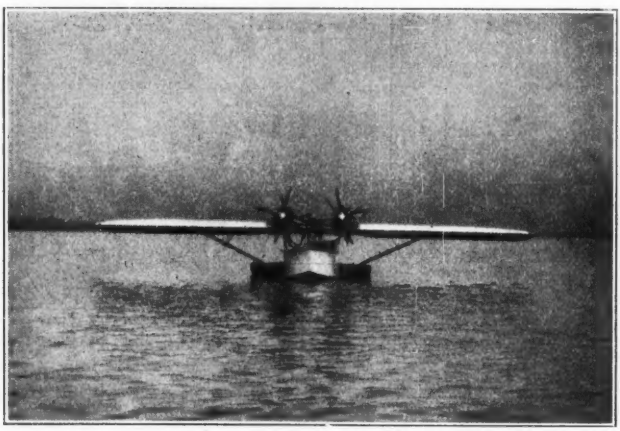

FIG. 8.

It has stumps and main wings of semi-cantilever construction. The engines are installed in pairs in tandem above the wings.

Unfortunately, the construction of the wings is not quite the same in the flying boats under comparision.

Type A has folding wings, as already stated, covered with sheet aluminium to the back spar (so-called " stressed covering "); from the back spar to the trailing edge fabric covering is used. The spars are of duralumin.

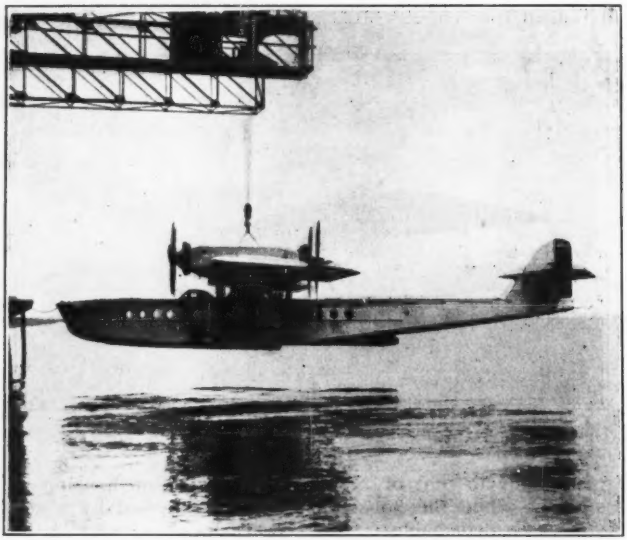

FIG. 9.

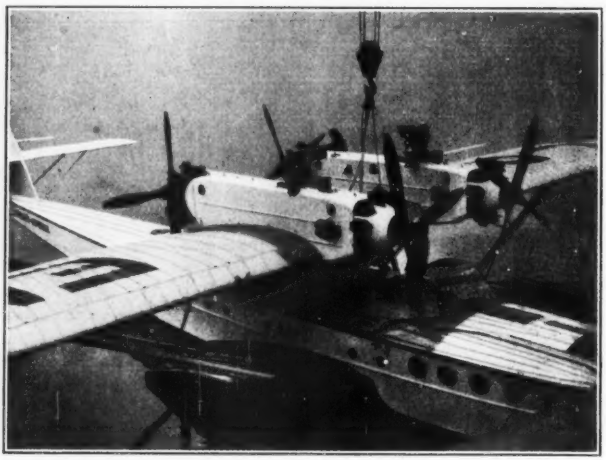

FIG. 10.

Flying boats B and C have similar spar construction but in high-tensile steel. Type B as box ribs of pressed and flanged duralumin sheet, and duralumin plating. Type C has framed ribs of duralumin and fabric covering except over the parts of the wings exposed to the airscrew blast.

Type D has wings in three parts for ease of transport, consisting of the nose piece, the middle piece and the trailing edge piece. Nose piece and middle piece are plated with duralumin while the trailing edge piece is covered with fabric.

The construction of the E type differs in having more than two wing spars. The possibilities of finer and lighter wing construction are exploited in this type and entirely new lines are followed. The most notable feature is that the wing covering is no longer permanently attached to the spars and ribs, but consists of large stiff self-contained plates, which are attached to the wing frames in an easily detachable manner.

Table II. contains the " tare weights " of the different boats. In " tare weight " is included the weight of the boat ready for flight, including necessary engine instruments and minimum sea equipment, but without equipment for special purposes. The weights of the various boats are divided into three parts, aeroplane structure, power plant, and necessary accessories. Weights are also given as percentages of the tare weight.

For easier survey the figures are also given graphically in Figs. 11, 12 and 13. The figures in Table II. are further analysed and the results given in Table III under the following sub-divisions.

" Frames " (Spanten) include all stiffening members transverse to the direction of flight. " Longitudinals " include all stiffening members in the direction of flight, excepting the U-shaped corrugations employed as stiffening in the sheet metal covering. " Skin " includes the plating and all sections whether transverse or longitudinal, serving to stiffen the walls of the boat locally including stringer angles, etc. The section " Miscellaneous " includes all items not properly included in other sections, *e.g.*, ports, doors, windows, clamps, wires, etc.

Table III. also gives the volume of the different hulls in cubic metres, the main frame area, and the surfaces in square metres. It is seen that the percentage weights of frames and longitudinals increases with size while the percentage weight of the " skin " decreases. The weight per cubic metre of the boat is 29.85 kg./m^3 for type A and only 18.3 kg./m^3 for type E.

In Fig. 14 this ratio is shown graphically against hull volume. The tendency of the curve is unmistakable, but it should be noticed that types A, B and C have no " longitudinals " in their construction.

Table IV. contains a similar analysis of the weights for the wing structure (wings and wing supports).

Tables V. and VI. contain more detailed data about fuel and oil weights for the different types on which the following remarks are made.

The fuel and oil tanks actually built into the different boats were not on a common basis and had to be reduced to a standard time of flight for comparison.

In Table II. the basis taken is 1.8 litres per horse-power installed.

Tables V. and VI. show how the reduction has been carried out.

The tank weight per litre falls off from 0.07 kg. per litre to 0.036 kg. per litre (aluminium tanks) as the volume increases from 50 litres to 16,000 litres. In a similar manner the tank weight per litre of oil falls from 0.31 kg. to 0.120 kg.

Table VII. gives the weight of the tail unit of the different boats. It is to be noted that the tail unit is sometimes entirely of metal construction, sometimes partly covered with fabric.

Consideration has been limited to the ratio of the weights of the various sections to the tare weight, for the different boats.

In meeting the fundamental question whether the performance of flying boats can be increased with their size, it is important to deal with the partial weights as well as with the tare weights on a systematic basis as in Fig. 15.

Structure Weight.

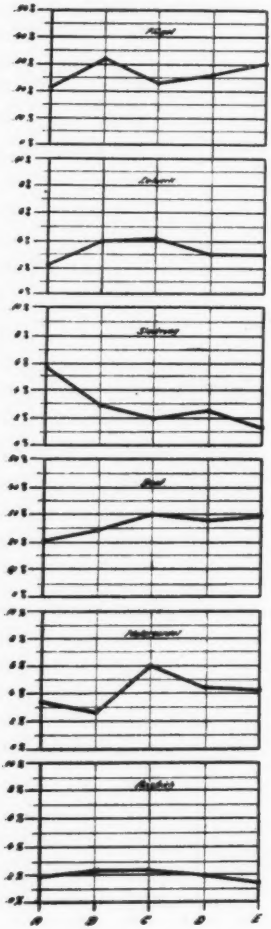

FIG. 11.

Wings.
Tail unit.
Controls.
Hull.
Engine nacelle.
Paint work.

Power Plant wt.

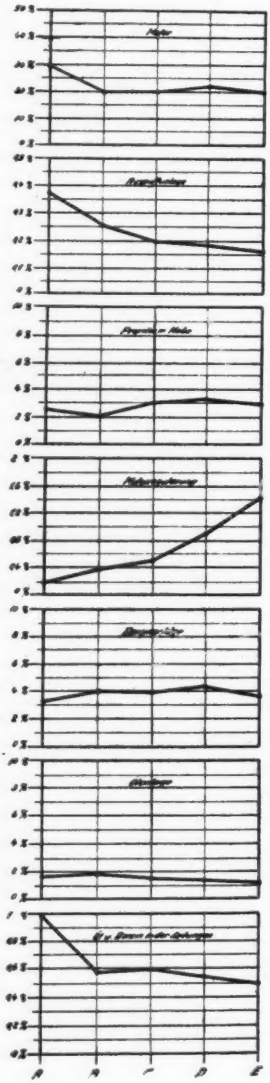

FIG. 12.

Engine.
Exhaust.
Airscrew and boss.
Engine controls.
Fuel system.
Oil system.
Oil and fuel in the pipes.

Essential Equipment.

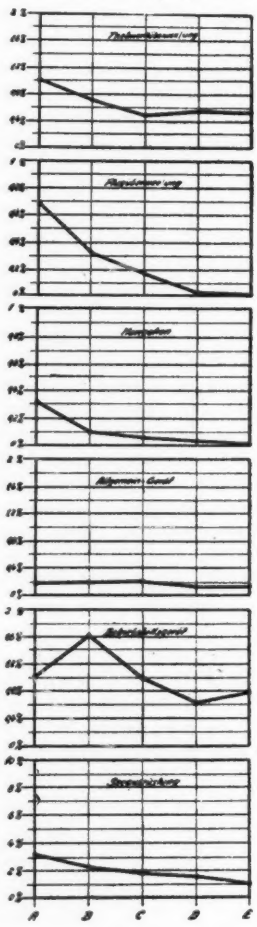

FIG. 13.

Power plant supervision.
Aeroplane supervision.
Navigation supervision.
General equipment.
Engine tools.
Sea equipment.

Graphical representation of Partial Weights as Percentages of Tare Weights.

TABLE III.

		Hull without stumps.					Stumps on			
		A	B	C	D	E	A	B	C	
Frames ..	wt. in kg.	26.46	97.91	264.64	621.73	2298.6	5.00	34.60	85.2	13
	wt. %	32.70	32.30	32.00	39.23	38.8	19.40	30.70	47.3	3
Longitudinals	wt. in kg.	—	—	—	89.43	731.5	—	—	—	
	wt. %	—	—	—	5.64	12.5	—	—	—	
Skin	wt. in kg.	53.55	194.00	538.00	831.17	2829.7	20.16	74.216	90.0	24
	wt. %	66.20	64.00	65.15	52.40	47.8	78.12	66.00	49.8	6
Miscellaneous	wt. in kg.	0.90	11.40	23.57	43.375	52.5	0.64	3.68	5.2	
	wt. %	1.10	3.70	2.85	2.73	0.9	2.48	3.30	2.9	
Total weight		80.91	303.31	826.21	1585.705	5912.3	25.80	112.496	180.4	38
Vol. (m^3)		3.16	13.30	32.70	92.00	351.5	0.420	2.70	5.80	
Wt. per m^3 in kg. ...		25.58	22.80	25.25	17.25	16.8	61.40	41.70	31.10	4
Hull surface, m^2		16.55	48.30	87.80	174.40	442.9	5.02	16.00	28.40	3
Wt. per m^2 of surface, kg.		4.88	6.28	9.40	9.10	13.32	5.14	7.04	6.36	1
Main frame area, m^2 ...		0.79	2.11	3.83	7.15	17.22	0.58	1.65	2.00	

umps only.			Hull with stumps.				
C	D	E	A	B	C	D	E
85.2	131.55	665.5	31.46	132.51	349.84	753.28	2964.1
47.3	34.40	50.3	29.50	31.90	34.70	38.30	41.0
—	—	157.5	—	—	—	89.43	889.0
—	—	11.8	—	—	—	4.50	12.5
90.0	242.356	482.0	73.71	268.216	628.0	1073.526	3311.7
49.8	63.60	36.4	69.10	64.50	62.44	54.60	45.6
5.2	7.74	18.0	1.54	15.08	28.77	51.475	70.5
2.9	2.00	1.5	1.40	3.60	2.86	2.60	0.9
80.4	381.646	1323.0	106.71	415.806	1006.61	1967.111	7235.3
5.80	9.50	43.50	3.58	16.0	38.50	101.50	395.00
31.10	40.10	30.50	29.85	26.0	26.20	19.38	18.30
28.40	37.00	95.00	21.57	64.3	116.20	211.40	537.90
6.36	10.28	13.92	4.96	6.46	8.67	9.32	13.45
2.00	2.82	7.38	1.37	3.76	5.83	9.97	24.60

TABLE II.

			A		B		C		D		E	
			kg.	°/₀ wts.	kg.	°/₀ wts.	kg.	°/₀ wts.	kg.	°/₀ wts.	kg.	°/₀ wts.
1	Wings with supports ...	Structural wt.	108.2	38.30	535.1	46.40	767.5	33.70	1898.9	39.50	7475.8	43.50
2	Tail unit		11.4	4.03	67.5	5.84	142.7	6.26	226.5	4.71	728.7	4.22
3	Controls		28.9	10.22	49.0	4.25	70.0	3.08	182.5	3.80	322.5	1.86
4	Hull		106.7	37.75	416.0	36.03	1006.6	44.40	2023.3	42.20	7235.3	42.14
5	Nacelles		17.5	6.18	46.5	4.02	205.0	9.04	329.6	6.86	1072.7	6.24
6	Paint work		10.0	3.52	40.0	3.46	80.0	3.52	140.0	2.92	350.0	2.04
			282.7	100.00	1154.1	100.00	2271.8	100.00	4800.8	100.00	17185.0	100.00
7	Engine	Tare Weight. Power plant wt.	148.0	76.25	335.0	68.23	670.0	67.30	1577.0	67.10	4721.0	66.15
8	Exhaust pipes		1.9	0.98	3.5	0.71	6.5	0.65	13.0	0.55	39.0	0.55
9	Airscrew and boss ...		13.1	6.75	36.0	7.34	100.0	10.05	239.6	10.18	720.0	10.01
10	Engine controls		1.0	0.52	6.5	1.32	17.5	1.76	65.2	2.77	350.0	4.90
11	Fuel system		16.9	8.71	69.8	14.20	131.6	13.22	320.4	13.64	919.0	12.86
12	Oil system		8.2	4.22	30.3	6.16	49.9	5.01	95.6	4.06	274.5	3.85
13	Oil and fuel in the pipes		5.0	2.57	10.0	2.04	20.0	2.01	40.0	1.70	120.0	1.68
			194.1	100.00	491.1	100.00	995.5	100.00	2350.8	100.00	7143.5	100.00
14	Engine supervision ...	Necessary accessories.	5.4	16.07	12.2	13.12	16.0	13.13	41.0	18.90	130.0	21.18
15	Aeroplane supervision ...		3.5	10.42	5.6	6.09	5.7	4.66	6.5	2.99	6.9	1.12
16	Navigation supervision ...		1.6	4.76	1.6	1.71	1.6	1.32	1.6	0.73	1.6	0.26
17	General equipment ...		1.0	2.98	3.6	3.83	6.9	5.66	8.3	3.85	30.4	4.96
18	Tools, engine		5.2	15.48	29.3	31.51	32.5	26.66	45.8	21.08	194.8	31.74
19	Sea equipment		16.9	50.29	40.7	43.74	59.2	48.57	113.9	52.45	250.0	40.74
	Total		33.6	100.00	93.0	100.00	121.9	100.00	217.1	100.00	613.7	100.00
			510.4		1738.2		3389.2		7368.7		24942.2	

TABLE IV.

WINGS.

Group Types.	A		B		C		D		E	
	Wt. in kg.	%	Wt. in kg.	%	Wt. in kg.	%	Wt. in kg.	%	Wt. in kg.	%
Longitudinals	27.608	25.20	194.00	36.30	352.5	45.85	818.5	43.15	3117.30	41.75
Transverses	13.694	12.70	—	—	189.0	24.60	319.0	16.80	2583.70	34.65
Wing covering	44.955	41.70	—	—	75.0	9.80	442.5	23.30	679.50	9.08
Miscellaneous	—	—	—	—	5.0	0.65	9.5	0.50	50.00	0.57
Complete aileron	3.480	3.30	17.29	3.26	29.0	3.80	62.0	3.25	188.00	2.52
Wing supports	18.400	17.10	73.50	13.74	117.0	15.30	247.46	13.00	857.30	11.43
Total	108.137	100.00	535.10		767.5	100.00	1898.96	100.00	7475.80	100.00
Aileron surfaces with balancing areas, m^2 ...	1.028		3.160		7.37		10.32		26.50	
Wing surface without ailerons, m^2	14.482		49.802		87.88		133.54		441.20	
Total lifting surface, m^2 ...	15.510		52.962		95.25		143.86		467.70	
Aileron wgt. kg./m^2 ...	3.390		5.470		3.93		6.00		7.10	
Wing wgt. kg./m^2 without ailerons	7.240		10.410		8.40		13.75		16.50	
Wing wgt. kg./m^2 with ailerons	6.970		10.120		8.05		13.20		15.97	

The covering of Types A and D is in metal.

TABLE V.

Type.	A		B		C		D		E	
H.P.	80		450		900		2000		6000	
Tank volume in litre	6		50		116		292		1302	
Total wgt. of tank installation in kg. ...	1.956		6.60		22.0		44		114	
Tank wgt./litre (kgs./litres)	0.326		0.132		0.245		0.151		0.088	
Tank volume/h.p. (litres/h.p.)	0.075		0.111		0.129		0.146		0.217	
Tank volume as % of fuel supply	12		7.95		7.4		7.56		8.14	
Tank volume as percentage of fuel volume reduced to common basis	8		8		8		8		8	
Total tank volume in litres	11.5		64.7		129.5		288		865	
Assumed tank wgt. per litre volume (kg./litres)	0.31		0.22		0.20		0.151		0.12	
Total tank wgt. (kg.)	3.6	43.9%	14.2	46.9%	25.9	52.0%	43.5	45.5%	103.5	37.7%
Wgt. of piping, including oil cooler (kg.)	2.7	32.9%	14.5	47.8%	20.0	40.0%	48.2	50.4%	160.0	58.3%
Wgt. of supports (kg.)	1.9	23.2%	1.6	5.3%	4.0	8.0%	3.9	4.1%	11.0	4.0%
Total wgt. of oil installation	8.2	100.0%	30.3	100.0%	49.9	100.0%	95.6	100.0%	274.5	100.0%

TABLE VI.

Type.	A		B		C		D		E	
H.P.	80		450		900		2000		6000	
Tank volume in litres, including gravity tank	50		530		1570		3860		16000	
Total wgt. of tanks in kg.	6.8		31.4		60.9		167.6		535	
Tank wgt. (kg./litre)	0.136		0.0498		0.0388		0.0434		0.0334	
Tank volume (litres/h.p.)	0.625		1.398		1.745		1.928		2.67	
Tank volume as % of fuel supply (standard)	1.8		1.8		1.8		1.8		1.8	
Total tank volume in litres (standard) ...	144		810		1617		3600		10800	
Assumed tank wgt. kg./litres	0.070		0.051		0.044		0.039		0.036	
Total tank wgt. (kg.)	10.0	59.4%	41.3	59.2%	71.2	54.0%	150.2	47.0%	389.0	42.3%
Piping and fittings (kg.)	5.36	31.7%	18.5	26.5%	34.0	25.85%	125.9	39.2%	410.0	44.6%
Supports (kg.)	1.50	8.9%	10.0	14.3%	26.4	20.15%	44.3	13.8%	120.0	13.1%
Total wgt. of fuel installation (kg.) ...	16.86	100.0%	69.8	100.0%	131.6	100.0%	320.4	100.0%	919.0	100.0%

TABLE VII.

Type.	A				B			
	Wt. in kg.	%	Surface in m^2	Wt. per m^2	Wt. in kg.	%	Surface in m^2	Wt. per m^2
Rudder fin ...	1.755	15.4	0.265	6.63	7.600	11.75	0.785	9.67
Rudder ...	1.100	9.68	0.398	2.77	7.200	11.15	1.200	6.00
Elevator fin ...	5.84	51.40	0.881	6.63	34.700	53.72	3.580	9.67
Elevator ...	2.68	23.52	0.932	2.88	15.098	23.38	2.385	6.35
Tail unit struts	—	—	—	—	—	—	—	—
Total	11.375	100.0	2.476	4.60	64.598	100.0	7.950	8.10

Type.	C				D			
	Wt. in kg.	%	Surface in m^2	Wt. per m^2	Wt. in kg.	%	Surface in m^2	Wt. per m^2
Rudder fin ...	32.50	22.77	2.38	13.63	48.78	21.56	4.20	11.60
Rudder ...	15.06	10.57	2.12	7.11	23.31	10.28	3.61	6.45
Elevator fin ...	56.75	39.72	8.40	6.75	88.38	39.00	13.06	6.79
Elevator ...	27.97	19.58	4.18	6.68	38.92	17.20	6.85	5.68
Tail unit struts	10.45	7.36	—	—	27.11	11.96	—	—
Total	142.73	100.0	17.08	8.35	226.50	100.0	27.52	8.17

Type.	E			
	Wt. in kg.	%	Surface in m^2	Wt. per m^2
Rudder fin ...	124.2	17.05	10.8	11.5
Rudder ...	47.15	6.46	8.32	5.67
Elevator fin ..	368.00	50.50	44.36	8.32
Elevator ...	114.05	15.65	12.72	8.96
Tail unit struts	75.30	10.34	—	—
Total	728.70	100.0	76.20	9.57

The entered tail units are metal covered.

The abscissæ are the lifting surfaces. The ordinates are the corresponding weights per unit area, of partial and tare weights of the different boats.

The lines joining the points show that type A lies outside the range of steady variation, for the simple reason that it has a Siemens-Halske engine, weight 1.5 kg. per h.p., whereas types C, D, E, F are equipped with engines weighing about 0.78 kg. per h.p. Reduction to a common engine basis gives a more continuous run of the curves as shown in the figure.

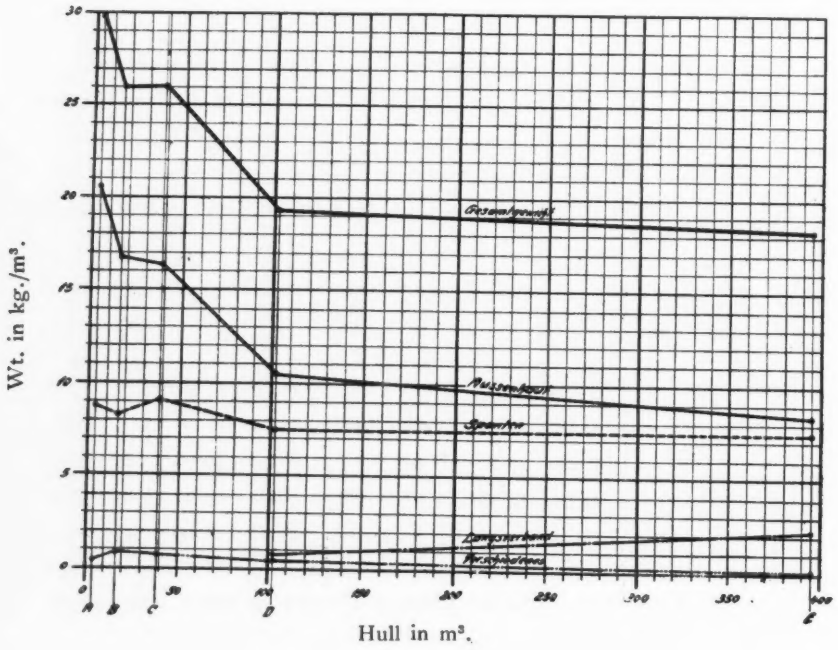

FIG. 14.

Curves, reading from top to bottom—
Total weight; skin; frames; longitudinals; miscellaneous.

In discussing these curves it must be noted that both A and B are all-metal, and are proportionately heavier than C, which is partly fabric covered. D is likewise heavier on account of the three section wing construction and preponderative metal plating.

Reduction to a common structural basis makes the curves much more continuous.

At first these characteristics show a rapid upward trend, for tare weight and for partial weights, but beyond type D they rise slowly. This may seem striking on a cursory view, but the apparent "kink" in the curves is due to the fact that the wing loading runs up rapidly at first, being nearly doubled from A to D, and then slowly, increasing only 10 per cent. from D to E. Later in the lecture more exact figures are given (Table VIII.).

TABLE VIII.

	Surface in m^2	Permissible max. wt. (kg)	Max. wt. reached	Permissible wt. per m^2	Actual wt./m^2	Difference	Tare wt.	Crew wt.	Total wt.	Disposable load	a=disposable load/tare wt.	1/a
A	15.5	670	780	43.2	50.3	110	510	80	590	80	0.157	6.38
B	52.9	2860	3175	54.0	60.0	315	1738	160	1898	962	0.553	1.81
C	95.2	6030	6400	63.4	67.3	370	3389	240	3629	2401	0.711	1.41
D	143.8	14100	15003	98.2	104.2	903	7369	320	7689	6411	0.871	1.149
E	467.7	51500		109.8		2500	24942	720	25662	25838	1.035	0.968

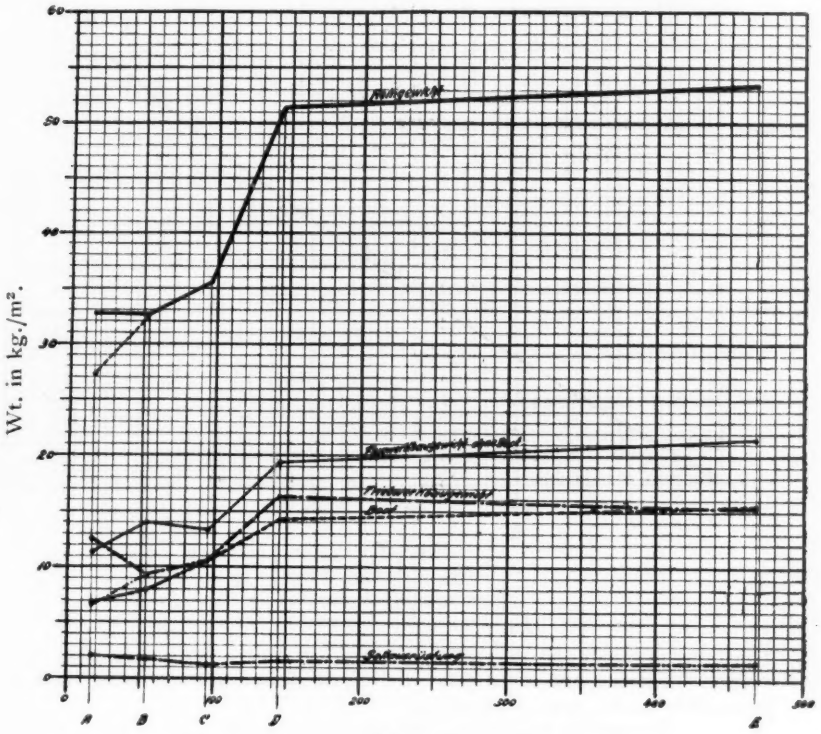

FIG. 15.

Lifting surface, including ailerons (in m^2).

Curves, reading from top to bottom—

Tare weight; structure weight without hull; power plant weight; hull; special equipment.

In Fig. 16 the tare weight is given as function of the horse-power installed. It is seen that the curve is nearly a straight line, which signifies that weight is nearly proportional to horse-power within the range of the family of similar boats here considered. Up to this point we have made a detailed analysis of the weight ratios of the various boats and have seen how the various partial weights of the flying boats vary under influence of increasing size, taking an account of certain structural differences. Further, question is now raised how the performance of flying boats varies with size in the three following respects:—

(1) The variation of the ratio, a = load/tare weight, that is, the disposable load per kg. tare weight, or the reciprocal $1/a$, that is the tare weight per kg. disposable load.

(2) The variation of the radius of action.

(3) The variation of the paying load with the radius of action.

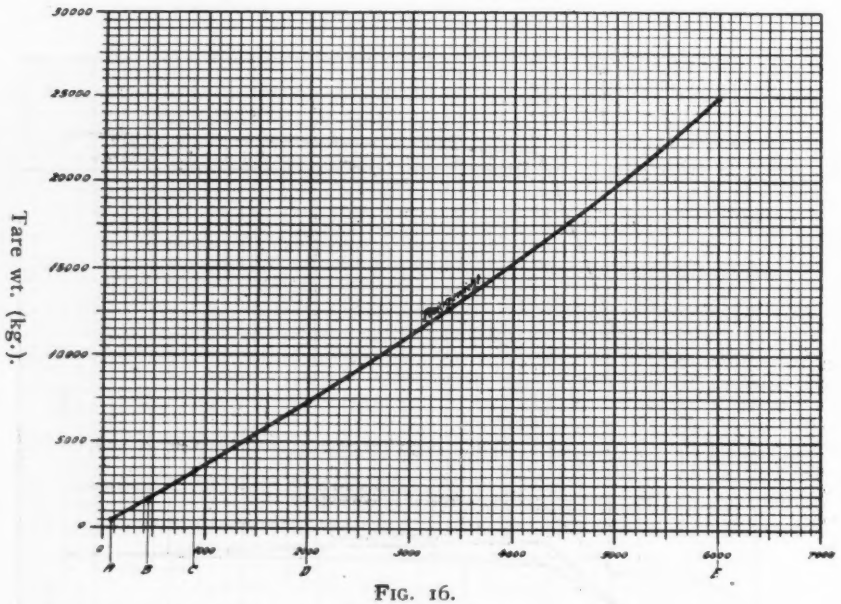

FIG. 16.
h.p. installed.
Tare weight curve

The rates of climb and the ceiling heights will not be considered here since the compression ratios and other details of engine design are controlling factors.

Disposable load is defined as follows:—

Disposable load = total weight − tare weight − crew.

Further:—

Useful load = disposable load − fuel and oil.

To fix the total weight of the various boats, two conditions must be observed.

First, the flying boats must be able to get off and fly with maximum load in the ordinary course of operation, and

Second, the structural strength must meet the load factors prescribed.

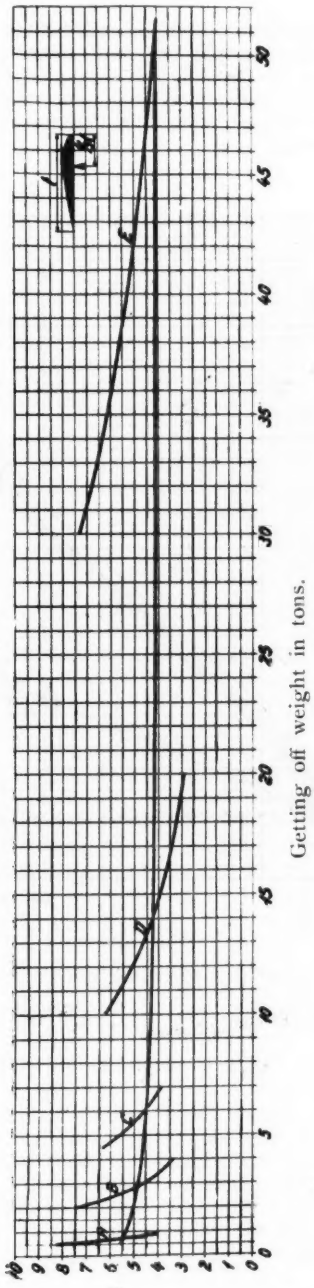

FIG. 17.
Factor of safety.

Fig. 17 shows the load factor curve for each boat in the case of normal flight (denoted as case A) plotted against the total weight; the curve of the lower limits of the load factors for the various boats is also drawn in accordance with the current regulations in Germany. Where this last curve cuts the former curves the maximum permissible weight is determined for the different types, within the prescribed load factors.

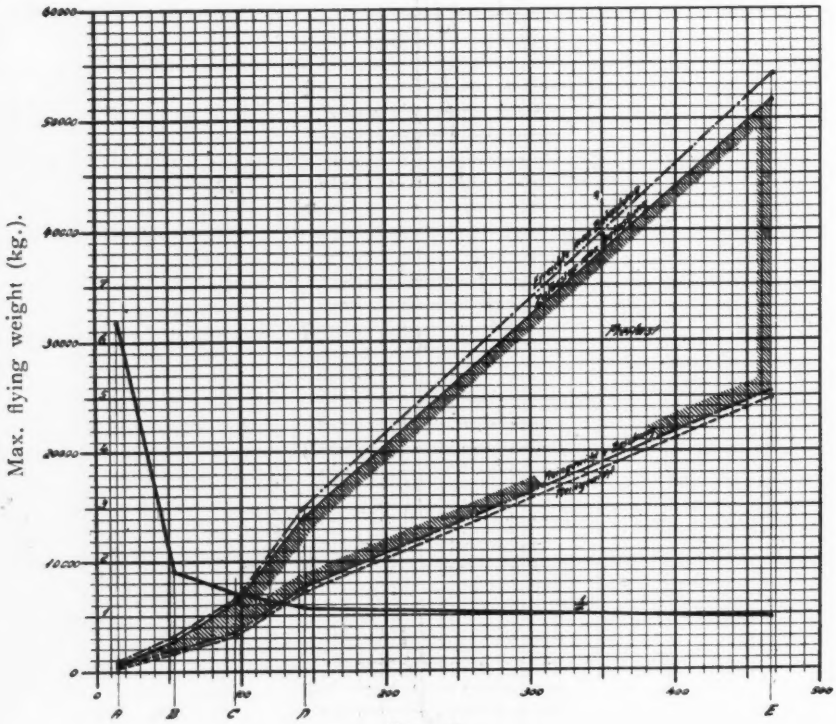

Fig. 18.

Lifting surface, including ailerons in m².

Curves, reading from top to bottom—

Max. weight reached; max. permissible weight; tare weight with crew; tare weight; 1/α. The difference of the ordinates shows disposable load.

In Table VIII. the maximum flying weights are given along with the corresponding total weights at the start, and the wing loadings. There are also shown the peak loads, that is the maximum loads with which it is possible to leave the water on a calm day. The increased loads reduce the load factors below the prescribed values and are only of design interest. In the last two columns are the disposable loads and the values of $1/\alpha$.

In Fig. 18 these values are shown graphically as functions of the area of the lifting surfaces. The shaded area gives, by the difference of the ordinates, the disposable loads. The values of $1/\alpha$ are also given graphically. One

kilogram of disposable load requires 6.3 kg. of structural weight in type A, only 1.2 kg. of structural weight in type D, and the figure sinks to 1 kg. of structural weight in type E.

TABLE IX.

Type	H.P.	V max.	V cruising	kg/km.	Rad. of action	Rad. of action corrected for increased tank wt.
A	80	137	110	0.136	587	587
B	450	162	140	0.596	1610	1566
C	900	191	160	1.050	2280	2195
D	2000	220	170	2.200	2910	2785
E	6000	240	185	6.100	4240	4042

In Table IX. are given figures necessary for further investigation—maximum speed, cruising speed on throttle, consumption of fuel and oil and radius of action.

The sections A to D are based on practical experience in long flights; those in section E are calculated and will be referred to later.

In Fig. 19 the radius of action is shown as a function of the wing area, and the increase of range with surface is evident; this relation cannot be

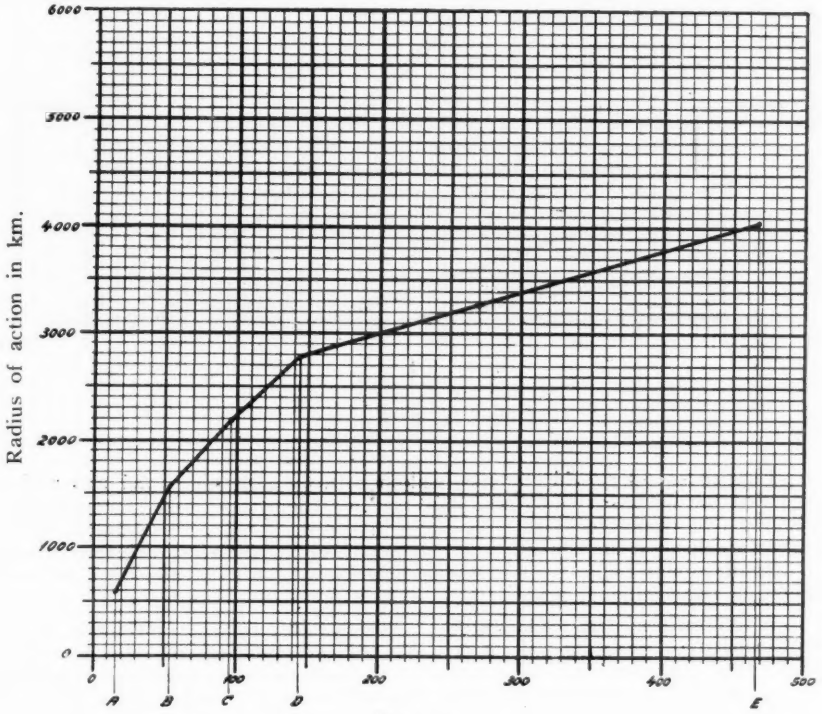

FIG. 19.

Lifting surface in m².

generalised without further discussion, but it is undoubtedly characteristic of the type of construction dealt with in this paper. On the other hand, the range of types A and B could be increased not a little for the smaller sizes by installation of a lighter engine in A and by using fabric covering to obtain a lighter wing in B.

It need hardly be stated that the fuel consumption is of great importance in determining the radius of action.

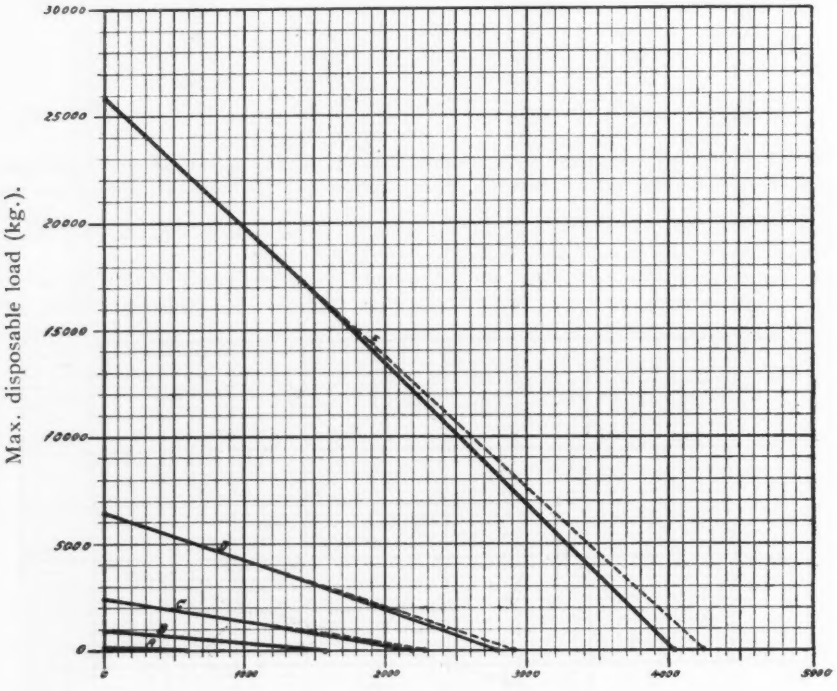

FIG. 20.

Radius of action in km.

Fig. 20 shows graphically the relation between disposable load and radius of action for the five types. The abscissæ are kilometres range, the ordinates kilograms of disposable load. Assuming a constant mean consumption, these curves are straight lines joining the maximum weight point (no radius of action) to the maximum range point (no disposable load). For greater accuracy the following rectification is made.

A uniform fuel tank capacity of 1.8 litres per h.p. was assumed and an oil tank capacity of .144 litres per h.p. This was not sufficient to allow the three larger boats to attain maximum range, so that additional tankage with increased weight had to be provided for flight beyond a certain range. This involved increase in tank installation weight and a corresponding reduction of the maximum range.

On the basis of uniform consumption the correction is easily made. The new curves are straight lines starting from the point where the original fuel supply became exhausted.

Their inclination is determined by the increased tank installation weight required per kilometre, and they cut the axis in the point of reduced maximum range. The difference is unimportant.

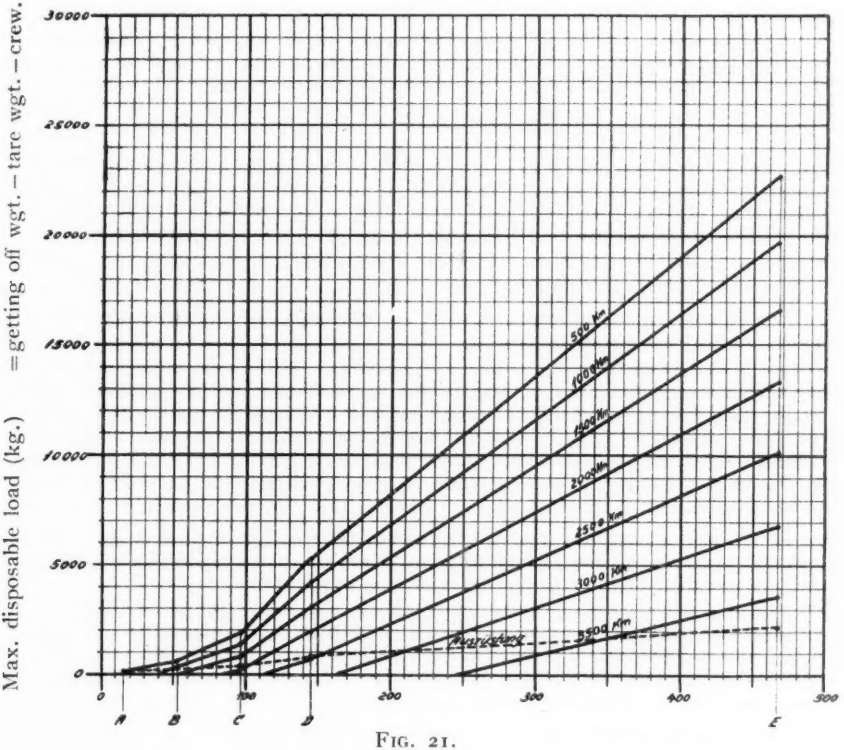

FIG. 21.

Surface in m².

Dotted curve shows special equipment.

In Fig. 21 the abscissæ are the areas of the wings and the ordinates are the disposable loads, taken from Fig. 20. A family of curves is given corresponding to ranges increasing by steps of 500 km.

The diagram shows clearly the results of increasing the dimensions.

	Range.	Disposable load.	Area.
Type A	1000 km.	0	—
B	,,	332	52m²
C	,,	1,351	—
D	,,	2,411	—
E	,,	19,738	465m²

In passing from type B to type E the area increases nine times, from 52m² to 465m², and the disposable load sixty times, from 332 kg. to 19,738 kg.

With a range of 2,000 km. we get the following figures:—

C	218 kg.	disposable	load.	
D	1,881	,,	,,	,,
E	13,378	,,	,,	,,

With increase of surface from 97m² to 465m², or about 4.8 times, there is an increase of disposable load from 218 kg. to 13,378 kg., or about 61 times.

Certain weights such as cabins, wireless, special equipment, and extensive mooring equipment are not included in tare weight, but in practice the disposable load is reduced by the weight of such installations. In Fig 21 the weight of special equipment for commercial transport is shown graphically in a separate curve.

The disposable load is to be reduced by this amount. It is seen from the figure that the larger the size the smaller is the relative weight of the special equipment. In boats C, D, E, the ratio special equipment/disposable load has the values 400/1,351=0.296, 900/4,200=0.214 and 2,200/19,738=0.111.

It is therefore possible to increase the weight of the cabins for comfort and of the navigational equipment for greater safety as the size increases.

To illustrate the influence of size on performance some examples will be given, using the diagram in Fig. 21.

1. It is desired to cover a course of 1,000 km. with 50 per cent. fuel reserve and complete equipment for mooring navigation and special purpose. What paying load can be carried? With 50 per cent. reserve the point at 1,500 km. is taken and we find that A, B and C are too small for the purpose. D gives a surplus load of 2,250 kg., while E gives a surplus of 14,400 kg. In other words, A, B and C can carry no paying load under these conditions, while D can carry 19 passengers and E 120 passengers, allowing 120 kg. per passenger.

2. A paying load of 3,000 kg. has to be carried 2,500 km. with 40 per cent. fuel reserve. Taking the 3,500 km. point, a paying load of 3,000 kg. is obtained for E while the other boats fall short of this requirement.

Besides the question of carrying capacity, speed and radius of action, it is of special importance to form some view of the seaworthiness of each boat. Seaworthiness is not a simple thing to define, and it is not at all clear what qualities are desirable. For the present and, it should seem, for a long time to come most experts would think it rash to lay down precise requirements.

As a personal opinion, the seaplane must be able to fly and to meet prescribed civil or military requirements. It must be able, with full equipment, instruments and crew, to carry prescribed loads to a given place in a given time (with reasonable latitude).

This implies ability to start under normal conditions.

Next in importance is the ability to make a forced landing, with skilful handling, and to ride all day in a sea of from 4 to 6.

Starting under such abnormal circumstances is not necessary and not worth striving after, taking a sea exceeding 3 to 4 as abnormal.

The reason for this opinion is that the materials of construction available at present do not afford the means of building flying boats in a rational way, strong enough to get off in a heavy sea without risk.

To meet such requirements the useful load and range would be so heavily reduced that such flying boats would answer no civil or military purpose and would therefore be practically worthless.

It is difficult to meet the one-sided demands of seafarers for continuously increasing seaworthiness in view of the tare weight imposed by economic considerations, yet increase of size opens a perspective of removing more or less completely the causes which very often lead to damage in a sea. This refers specially to the frequent damage to running airscrews by waves.

Table I. gives the height of the airscrew disc above the water-line. For the five types under consideration these are :—

A	...	...	0.72 m.
B	...	...	1.40 ,,
C	...	...	1.81 ,,
D	...	...	2.24 ,,
E	...	...	6.45 ,,

It is easy to see the advantage of type E in this respect with its airscrew 6.45 m. above the water-line, $3\frac{1}{2}$ times that of the C type—1.81 m. This is equally important for the engines. In the 1926 seaplane meeting at Warnemunde a B type flying boat was taking part in competitions when a wave broke over the engine, filled the carburettor with water and put the engine out of action, just when full power was required for getting off.

With increase of height of the carburettor from 2.5 m. above the water-line, in the B type, to 3 m. in C, and 7.8 m. in E, the reduced risk of such a mishap is evident; pilots and mechanics are increasingly safe from seas washing over their positions. At the same time, comfort, endurance and ability to carry out repairs in rough weather are all increased.

Spares, tools and elbow room are all needed for carrying out repairs.

As an example, if type C is flying on a 500 km. stage, with 50 per cent. fuel reserve and special equipment, Fig. 21 gives a disposable load of about 1,100 kg., of which a spare airscrew of 50 kg. wgt. takes up 5 per cent. A spare engine of 330 kg., taking up more than one third of the disposable load, would be out of the question.

For types D and E, with disposable loads of 3,200 kg. and 14,500 kg. respectively, a spare airscrew for each pair of engines would take up 3.75 per cent. in type D and 2.48 per cent. in type E. A spare airscrew for each engine would be excessive.

One spare engine for type D and three for type E take up respectively 12.3 per cent and 8.2 per cent. of the disposable load. These figures illustrate better than words the advantages to be expected with confidence from increasing size.

Seaworthiness and reliability in working are actually increased by carrying increased personnel, and our examples show that the possible increase of personnel goes up with the size of the boat.

SUMMARY.

The data of five flying boats of widely different sizes, but of similar construction, are given in tables showing the weights of component parts.

The tare weights and partial weights are given graphically as functions of wing surface and hull volume.

Permissible flying weights are obtained for prescribed load factors, and test performances in starting and flying, and the disposable loads are found for the different types. Using average values of actual consumptions and speed, the relations between radius of action, disposable load and wing area are obtained.

There is a slow increase of range and a rapid increase of disposable load with size. Obviously the crew, equipment and instruments take a smaller fraction of the tare weight and of the disposable load with increasing size.

For critical appreciation of the data presented it is again expressly stated that all the weights and performances for types A to D are taken from actual experience. The figures given for type E are based on calculations with a wide margin on the safe side.

To estimate their value in discussing the advantages of increased size, the possible sources of error should be gone into more closely.

With regard to the tare weight, the power plant weight, including airscrews, instruments and fuel installation, is accurately known within 5 per cent.

The weight of the hulls, wings, and control units are obtained from complete working drawings. A large proportion of these figures have been checked by subsequent weighing of the finished parts. The discrepancies were so small that no correction is necessary.

The only weights which cannot be directly measured are the paint, caulking material, internal fixtures and equipment.

In this paper the tare weights have been intentionally kept as free as possible from items of equipment and internal fixtures, so that no serious error can arise on this score.

The weight of painting and caulking was estimated from years of experience. It is estimated that the error in the tare weight of type E cannot exceed ± 6 per cent., taking into careful account every possible source of error.

The same accuracy is claimed for the performance. In carrying out the aerodynamical calculations all the most up-to-date results and methods were used.

So far as predeterminations of flying speed and weight are concerned, calculation and test performance have always agreed in my personal experience. In no case for many years have these flying boats failed to get off with greater loads than were specified in the design.

Discussion

The Chairman, in expressing gratitude to Dr. Dornier for having come to this country specially for the presentation of his paper, said that by so doing he had paid a great tribute to the Society. There was no other body of its kind in any other country that was so honoured by having men such as Dr. Dornier, from other parts of the world, coming here and giving the results of their experience. Technically, no doubt, those taking part in the discussion would disagree with Dr. Dornier on some points, but they would all thoroughly applaud the immense initiative and courage which he and those who had supported him had displayed in the development of the flying boat. We in this country required flying boats far more urgently than Germany did, and when we considered our position *vis-à-vis* all these developments, it gave us a great deal to think about. The exhibition of commercial aircraft which was held outside Berlin a few days ago, prior to the inauguration of the Luft Hansa summer services clearly indicated what some of us knew already, namely, that Germany was setting out to capture air traffic outside German waters, and Dr. Dornier was one of those who were producing the type of craft that would enable her to do so.

Colonel Mervyn O'Gorman: Great interest attached to the figures which had been given in the paper, notably perhaps those regarding the big type E flying boat. Rumours had been rife in this country over that particular boat, and it was a pleasure to have Dr. Dornier present in person and to have from him the facts with circumstantial detail which carried conviction. He asked for information with regard to total gross weight and the wing loading of the E

type, because he believed it worked out at something of the order of 30 lbs. per square foot—it would seem difficult for the craft to leave the water at all. It was notable that in the very large size, instead of requiring 6 lbs. of total aeroplane to transport 1 lb. of man, it became possible to do this with 1 lb. of aeroplane tare weight. That was a phenomenal alteration of the position.

Major BUCHANAN: The figures given by Dr. Dornier were so numerous that they would require very close study before one could express any opinion from the technical point of view. The cursory examination of the figures would lead one to think that perhaps Dr. Dornier was a little optimistic; it would certainly appear, from observations we had been able to make in this country, that Dr. Dornier was looking for more than he would ultimately achieve, but if he got anywhere near the goal he hoped to reach he would have advanced very much further than anyone else in the world in the design of the large flying boat. That in itself would be an achievement which would justify the work he had put into it, and would enhance Dr. Dornier's reputation still further in the world of aviation. One hoped, however, that he would achieve what he expected to achieve, even though one might believe that he would have to be content with something a little less. He asked Dr. Dornier for information as to the efficiency of the tandem arrangement of propellers. That was a very vexed question which had been discussed in the technical Press recently. It had been the subject of many wind tunnel experiments, and if the results obtained in the wind tunnel were fully confirmed full-scale, the use of tandem propellers involved a material drop in propulsion efficiency. So far as the experiments had gone, they seemed to lead to the conclusion that there was a loss of something of the order of 5 per cent. in the efficiency at top speed by this arrangement, and a little more on climb. On the super Wal machine there were four Jupiter engines arranged in tandem. The question as to whether air-cooled engines could be used as efficiently as the pusher types had also been the subject of much discussion here, and any information which Dr. Dornier could give as the result of his experience in that direction would also be much appreciated. We had made experiments on the use of stump planes and, quite frankly, had come up against difficulties in maintaining lateral stability. The tests showed that with stump planes there was a period of lateral instability at certain speeds and under certain water conditions, such lack of stability being sufficient in some cases to overturn the machine, and it would be interesting to know whether Dr. Dornier had experienced that difficulty and whether he had been ingenious enough to overcome it.

Mr. SHORT: In this country, up to the present, we had not developed the bigger monoplanes and, consequently, we could not visualise their possibilities with the same assurance as could Dr. Dornier with his extended practical experience and knowledge. We were now building some fairly big monoplanes, however, and we should have an opportunity of comparing their performances with those of the big biplanes that had been developed in this country to a considerable degree of efficiency. There was one conviction which Dr. Dornier himself and many others had in common, and that was the conviction that we had by no means reached the limit of size to which the flying boat could be developed with advantage. He could not refer to the aspirations of his own firm in this connection, but his conviction was backed up by scientific research work carried out by a very able chief designer and a technical staff of long and practical experience. Even if he were able to criticise some of the assumptions Dr. Dornier had made regarding these very big machines, he would not feel inclined to do so, because the best answer to all pessimism based on theory was to build a machine, and that was what Dr. Dornier was doing. Whether or not it proved as successful as Dr. Dornier expected, the fact remained that the experiment would be a very valuable one, from which we should all gain knowledge. He asked Dr. Dornier why he had a preference for steel spars. It was

known that there was a theoretical saving in weight by using steel for spars, but we in this country had developed a very satisfactory duralumin spar which up to certain dimensions appeared to offer advantages. There was the possibility of using this material in a laminated form, which enabled us to taper off the thickness, and consequently to reduce the weight of the spar, as the stresses permitted. Another factor was the ease with which the material was worked and riveted, and most satisfactory results had been obtained from corrosion tests over a long period. Dealing with Dr. Dornier's reference to caulking—by which was meant, presumably, the packing of the joints of the plates of which the hull was built—he said it was well known in this country that we had developed a form of boat in which the skin alone bore the main stresses, and in jointing the plates together we had not found it necessary to use any form of caulking, for perfect watertightness was obtained without it. He could not help thinking that we had saved time, labour and money, and that we obtained a better and stronger joint.

Mr. FAIREY: The remarks of Colonel O'Gorman might give the impression that in the present stage of aircraft development in this country 1 lb. of aircraft was needed to lift 1 lb. of passenger. He believed our structure weights had always remained somewhere between 28 and 35 per cent., and we did not need anything like 1 lb. of aircraft to lift 1 lb. of passenger. If we started at that point we should have a long way to go. The relative efficiencies of the biplane and monoplane types of machine, he continued, had yet to be proved. He asked Dr. Dornier what he proposed to do about the power plant in the large size machines he hoped to produce. He had now 12 engines, which meant that there were 12 throttles, 12 ignition controls and altitude controls, which had to be operated by somebody, and in operating them one would have to achieve a dexterity resembling that of M. Paderewski in operating a piano. Was it proposed that as machines became larger we should have to continue to instal a vast number of comparatively small engines or was it proposed merely to use these comparatively small engines in the interim, until really large power plants became available? If, in the big E type machine, Dr. Dornier were to utilise six instead of 12 engines, then the seaworthiness would be reduced, because the diameter of the propellers would have to be increased. It would add very greatly to the value of an already valuable lecture if Dr. Dornier would give us some enlightenment on that point.

Mr. A. V. ROE: Had Dr. Dornier found that the rear propellers were more liable to be broken than were the forward propellers, especially in the case of out-board engines? With regard to wing loading, he asked if Dr. Dornier expected to approach anything like 30 lbs. per sq. ft. of surface? Has Dr. Dornier considered, or have tests been carried out to determine the loss of efficiency due to the air being compressed between the main plane and hull?

Mr. NORTH: He had had no experience of flying boat construction, and had had only one experience of seaplane design, but after he had left hospital he had not proceeded further with it. At first sight Dr. Dornier's figures appeared to suggest heresy, but he believed it would be found, when they were studied carefully, that most of what appeared to be startling was due to a mode of statistical presentation which was unfamiliar to us. Aeronautical engineers could not be too grateful to Dr. Dornier for having presented such a paper, because it contained a mass of statistical information which it was difficult to acquire and which was very seldom given out for the benefit of engineering in general. The acquisition of such information had a very valuable stimulating effect on the thoughts and the work of all engaged in aeronautical engineering.

Major BUMPUS: He believed that on no previous occasion had the members of the Society been presented with data relating to a series of actual boats

produced on the same lines by the same designers, so that actual comparisons could be made, and which gave them something definite on which to form their ideas as to the lines of development of large machines. From time to time there had been discussions as to the change in structure weight with size of machine, and various limits had been laid down which it was said could not be exceeded, but Dr. Dornier's paper had given concrete examples on which to base an opinion on that particular question. He asked whether any part of the advantage which Dr. Dornier claimed for the large size machines was due to an appreciable decrease in factors of safety. It was generally recognised that with the larger and less manœuvrable machines a reduction might be made, but the extent of the reduction might affect materially the proportion of gross weight available for paying load. With regard to wings, he said that a number of monoplanes had been built, both in Europe and America, but in the great majority of cases the wings were tapered both in width and in thickness. That was generally considered to be of advantage aerodynamically and also structurally, chiefly since those parts of the wings where the bending moments were greatest had the greatest depth. It was notable, however, that Dr. Dornier, who had had more experience perhaps than anyone else in the construction of monoplanes, had adhered consistently to the parallel plan form. Was this only because that form of construction was cheaper, or did he feel that it was as good aerodynamically and possibly almost as good structurally as the tapered form?

Mr. MITCHELL: He was very pleased indeed to learn that in the opinion of Dr. Dornier the structure weight of flying boats decreased with size, and that as the size increased longer ranges and greater disposable loads would be obtained. His own small experience had led him to the same opinion, in spite of the statements made by various theorists to the effect that structure weight would definitely increase with size. Discussing the position of the fuel carried in the machines, he said that British flying boats were now designed almost exclusively to carry the fuel in the wings, and no fuel was carried in the hulls, and it was interesting, therefore, to note that Dr. Dornier's flying boats carried their fuel in the hulls. He strongly suspected that Dr. Dornier's method of stabilising made it necessary to have a very low centre of gravity, and that that was the reason why the fuel was carried in the hull. He asked Dr. Dornier if he would give some details of his experience regarding the sea water corrosion of duralumin.

Mr. WYN-EVANS: Reference was made in the paper to "prescribed load factors" and to "current regulations in Germany," and he presumed Dr. Dornier's designs met the requirements of those regulations. He believed the German civil authorities must consider a material failing stress in excess of the yield compressive stress for duralumin and steel, otherwise their requirements for stressing flying boat hulls appeared to be very severe. Assuming the yield compressive stress for duralumin was of the order of 16 tons per sq. in. there was evidence of structural instability producing failure at less than half this, and it would be interesting to know what point on the stress strain curve Dr. Dornier took as the failing stress in compression to meet the aforementioned requirements. Again, the German civil authorities, he believed, demanded what they termed a "safe landing factor," and this was of great importance in dealing with the skin stresses. The formula they used, he believed, was as follows:—

$$e = K\,[V_L^{1.5}/W]$$

where e = the "safe landing factor."
V_L = the landing speed.
W = the all-up weight.
K = a constant depending on sea conditions.

Reference had already been made to the international scale for "seas"—Nos. 3, 4, 5 and so on—and the "safe landing factor" was used in several German formulæ and therefore was important. Over and above this factor a breaking factor of 2 was required. He asked if Dr. Dornier could say what sea conditions he usually assumed as the basic assumptions for his designs. A third point influencing the weight of structure was the criterion for thin plate stresses. Much had already been done by eminent German authorities, and all their formulæ were of the form :—

$$f = m\,(pb^2/t^2)$$

where f = stress in plate.
p = fluid pressure on the plate.
b = breadth of the plate.
t = thickness of plate.
m = a constant depending on the ratio of the length to breadth of the unsupported area.

Obviously these formulæ did not take into account the relieving effect of the tension developed in the plate. It would be interesting to know what exactly Dr. Dornier accepted as a basis for his skin stresses due to fluid pressure.

Mr. SPANNER: The whole of Herr Dornier's paper presents itself as an example of constructive work, carried out on lines very familiar to a naval architect.

He must congratulate Herr Dornier on the extremely ingenious manner in which he has provided for the transverse stability of his flying boats, when they are at rest, or moored in a seaway. It is perfectly obvious that the centre of gravity of the machine is a considerable distance above the waterline, and the short lower stumps offer a most ingenious method of increasing the transverse inertia of the waterplane sufficiently to ensure stability.

At the same time, however, experience with marine vessels of various designs leads one to regard with some degree of doubt, the ability of the projected "E" machine to remain stable and seaworthy in anything approximating to moderate sea conditions.

The cinematograph film which purported to show the operation of a flying boat in a "rough sea," owed a good deal of its striking character to the instability of the platform from which the film was taken. Anyone familiar with observation of ships in waves would at once focus their attention on the profile of the flying boat hull which was moving through the water, and from study of the bow of the boat in the film shown, it certainly did not appear that there was anything in the nature of even moderate waves to interfere with the passage of the craft; in fact the "rough sea" appeared to be simply a short choppy disturbance such as one might meet with on an enclosed area of water.

The problem actually to be faced, of course, with British machines is that of getting off if such conditions are superimposed upon either a long or short swell.

Another aspect of the question has to do with the interaction between boat and plane in different circumstances. For instance, when the craft is in the air it is obvious that the boat is depending below a strong wing structure carrying heavy engine loads, the boat itself imposing such stresses upon the connecting elements as result from the forces necessary to drag it more or less smoothly through the air in a straight or in a curved direction.

When the machine is resting on the water, assuming the water to be disturbed by a short swell for instance, it is obvious that the rolling and pitching which occurs must involve continual sudden sharp stresses between the hull and the wing structure and engine supports, this by reason of the fact that these heavy weights, fairly high up, are jerked to and fro through wide angles, by

the rolling imposed on the hull by the wave forces. Those who have been in some small craft, say a pinnace, "lying to" in the Solent or at Spithead, will realise what is meant with regard to the jerky character of the stresses thrown upon masses some distance above the centre of oscillation of the hull of the boat.

In a craft of the size of the projected "E" machine, one is inclined to think that these inertia stresses will assume formidable amounts, while they will be of more or less periodic alternating character and, as such, likely to give rise to fatigue stresses such as we find continually in ship structures.

Unless a flying boat can be moored safely in such conditions as must occur when it is operating on any coastal or otherwise exposed route, the machine is likely to spend more of its time being repaired than in flying, for the most optimistic estimate can only lead one to the conclusion that flying boats will spend four or five hours as "boats" for every hour they spend as "flying boats."

Sir SEFTON BRANCKER: He had done a good deal of flying on the standard Dornier Wal with the Italian companies who operate in Southern Europe. On one occasion a piece of the exhaust pipe had fallen through the back propeller, putting the rear engine out of action. The machine flew quite comfortably with a full load for 15 miles and landed. After the passengers had been disembarked and the load lightened, she took off and flew home to Pisa on one engine. He had a great admiration for the Dornier Wal. She was very comfortable, handled extremely well in the air, and on the water was very seaworthy. The "stump" system appeared to give great stability on the water and, in addition, provided a most useful platform for embarkation and disembarkation and for handling the machine whilst on the water. He was actually in the throes of trying to evolve specifications for future experimental commercial aircraft and, therefore, Dr. Dornier's figures were of particular interest to him. He thought that we must all admit that in the development of the monoplane we were behind other countries; but he hoped that, when we had had a full opportunity of studying Dr. Dornier's figures closely, we should learn a good deal and make further progress. He would like to hear Dr. Dornier's reasons for having stuck to monoplane design so wholeheartedly, and he would also like to know his views on the value of metal covering for the wings. In his early models the wings were all metal. In the super Wal the trailing edge and the rudder were fabric-covered, and in the body of the paper, when discussing the big machine, he believed Dr. Dornier had indicated that a good deal of further weight could be saved by using fabric covering. He had always felt himself that complete metal covering would be the best system, if it could be made light enough, and that this metal covering should take a very definite share in the strength of the wing.

Colonel FELL (*contributed*): He noted the importance which Herr Dornier attached to the reduction of fuel consumption and its influence on range. He was, therefore, somewhat surprised to note that in all the experimental boats referred to comparatively low compression air-cooled engines were fitted. In none of these engines could the consumption have been much below .6 lbs. per b.h.p. hour. This feature is especially surprising in view of the fact that Germany was the pioneer in the low consumption high compression engine. So long ago as 1916 the B.M.W. Company produced a six-cylinder in-line water-cooled engine which was fitted with a dual carburettor system and a compression ratio of over 6:1. As a result of tests on this engine at the makers' works, which were subsequently confirmed by experiments at the R.A.E., Farnborough, a consumption of about .44 lbs. per b.h.p. was shown—a petrol consumption which so far as he was aware had never been equalled on any other complete petrol engine either before or since. No special fuel was required for this engine and though its weight per b.h.p. was on the high side, this could be reduced in the light of up-to-date experience.

In his opinion the development of the high compression engine was of vital importance to the future of the long range flying boat, as only by this means could good economy be obtained. As a result of all bench tests carried out so far, it had been demonstrated that the fuel economy with the water-cooled engine for a given compression ratio was lower than that obtainable from an air-cooled engine; further, the water-cooled engine was capable of utilising a higher compression ratio than the air-cooled engine owing to the lower tendency to detonation with the former.

It would be interesting to know in view of the above why Herr Dornier should prefer the air-cooled engine for the long range boat.

Major RENNIE (*contributed*): In Table I. the propeller clearance of type E is given as 21.2 ft. A rough layout of the boat would give this dimension as the distance from the L.W.L. to the engine crankshaft centre. Would Dr. Dornier kindly say if his dimension is correct? Also in the same table the power loading of type E is given as 18.8. As this corresponds to the horse-power loading of the normal type of flying boat as constructed in this country, but with an overload of about 20 per cent., one would expect the take-off to be poor under favourable conditions and uncertain, if not impossible, under unfavourable sea conditions. Again, one would expect type E to be less efficient aerodynamically than type D, owing to the increased number of engines, yet the top speed is higher with a higher h.p. loading.

With regard to wing and power loading. If operations have to be carried out under average sea and weather conditions, then experience shows fairly definitely, with the present size of boats in service, that the taking-off speed should not exceed 55 knots and the power loading should be about 15 lbs./h.p. as a maximum. However, it does not follow that a high wing loading necessarily means a high taking-off speed. In the design of a multi-engined monoplane boat it is possible to arrange the engine positions to obtain the maximum slipstream effect on the wing, and as the take-off is usually with full throttle, advantage should be taken of the slipstream, as its presence cannot be avoided. For example, take the case of a multi-engined monoplane boat of gross weight 63,500 lbs., the taking-off speed not to exceed 55 knots. Then, apart from air performance consideration due to wing loading, we obtain the following values for wing loading for a constant taking-off speed of 55 knots with various proportions of the wing in the slipstream:—

Percentage of wing in slipstream.	Wing loading lbs. sq. ft.	Effective k_1 max.	Span in ft. for A.R. 6.
0	12.3	0.6	176
5	12.9	0.63	171
10	13.6	0.66	167
15	14.2	0.69	163
20	14.8	0.73	160
25	15.5	0.76	157
30	16.1	0.79	153
35	16.8	0.82	150
40	17.4	0.85	148
45	18.0	0.88	145
50	18.7	0.91	142

The landing speed would, of course, be higher, but even then a landing is usually made with the engines throttled back, the effect of which again is to increase the effective k_1 max., so the speed in this case would probably be between 60 to 65 knots, a quite acceptable figure for a boat of this size.

Mr. C. C. WALKER (*contributed*): Although the author disclaims any theorising about the effect of increasing dimensions, yet he does, as everyone

must, draw some general conclusions from the results of his work. One might say that one of his most important conclusions is that disposable load (whether referred to h.p. or surface) increases with size in the boats he has built and is building. This is undoubtedly the case, but it is important that no general inference that an increase of size means an increase of disposable load should be drawn from these examples which vary extremely in the quantities which determine their behaviour and performance.

The flying boat is certainly a different proposition to the land machine, the latter having to possess (in the interests of safety as well as international regulations) a certain limiting get-off which in its turn demands a certain reserve h.p. and climbing speed. The effect of increasing the size of the land machine, which in order to maintain its get-off must preserve the balance between h.p. and surface loading, is a rapid increase of structure weight after a certain size is passed. In his boats Herr Dornier has evaded this inevitable increase by greatly increasing his minimum speed and cutting down his angle of climb. This, however, has nothing to do with dimensions, and there is no reason why the smaller boats should not also undergo this process, unless in the smallest the rapidity of the angular movements would make control too difficult.

If one of the smaller boats, say type C, were designed to the same h.p. and surface loading as type E, it is obvious that it would have a great relative disposable load. This will be readily appreciated from the fact that the (structure wt./total wt.) of type C is only about 4 per cent. more than that estimated for type E, although its h.p. and wing loading would give it a climbing angle nearly as steep as a commercial land machine. The wing loading of type C is about 13 lbs./sq. ft. and of type E 22.5 lbs./sq. ft. Type C has therefore a margin of $8\frac{1}{2}$ lbs./sq. ft. available for increased load, some increase of structure weight to carry it, and the necessary modification of the engine power to bring it into line with the weight per h.p. of type E.

This aspect of the question has been rather emphasised, not because of anything said by Herr Dornier in his paper, but because one has heard it suggested that these experiments have rather exploded the idea of the increase of structure weight with size. This is so far from being the case, that it would be much truer to say that the designer of a 6,000 h.p. machine is forced to adopt very high loading and landing speed in order to evade this increase and make the big machine a possibility.

Type E is a most interesting and courageous experiment and one must suppose that Herr Dornier has satisfied himself that it can leave the water and reach the 80 m.p.h. on the water or thereabouts, which would be necessary to get off. Had the span been given in the paper it would have been possible for anyone to have formed their own idea of the performance. If the author's estimate of the top speed be accepted and similarity of wing proportions to type D be assumed, then it appears that the rate of climb at sea-level would be about 400 ft./min. with an absolute ceiling of about 10,000 ft. This climb at a forward speed of about 105 m.p.h. after a very long run to get off, seems to demand a rather special route for its operation, containing big stretches of sheltered water free from shipping. Herr Dornier has achieved a remarkably light wing construction in all these models. Type D, for example, appears to carry a (failing) load of 79 lbs./sq. ft. and to weigh only $1\frac{1}{4}$ lbs./sq. ft.—a result which indicates a high economy of material.

The use of high wing loading is, of course, much more adapted to sea than land planes, but it is not possible to say in what way this feature would have naturally evolved in this country as until recently there was an official prohibition of a controlled minimum speed greater than 55 m.p.h., though a wing loading of 17 lbs. per sq. ft. with a weight per h.p. of 16 lbs. was used experimentally here in 1921. It may be said, perhaps, that fears about high wing loading have

tended to be exaggerated in this country, although for land machines a substantial reserve h.p. is necessary.

A general survey of the types described in the paper makes one think that Germany must be a sort of designer's paradise. This, of course, may be a mistaken view, because the difficulties of policy are not displayed, but it does seem clear that the author has been able to steadily pursue his own ideas without influence from outside. In this way the most rapid progress is made, the designer can use his past experience to best advantage, and his results form a coherent plan of development. But how can a designer have this free hand when the expenditure of considerable sums of money is involved? This is difficult to understand. If Government money is available for this type of research, the department spending the money draws up the specification. If a transport company requires a new type it cannot take chances and has a clear idea of what it wants. Rapid deliveries and guaranteed performances preclude any considerable departures from standard practice. The only way here of developing one's own ideas is to do so at one's own expense.

Captain SAYERS (*contributed*): The remarkable increase in range and in useful load with increasing size for the Dornier family of flying boats, seems at first to be at variance with usually accepted ideas concerning the increasing percentage of structural weight which should accompany increasing dimensions in aircraft.

The volume of data given in the paper is very large, and in some ways a little difficult to analyse, but it is perfectly clear that despite the general similarity of the design of all the five boats complete structural similarity is not even approximately maintained.

The theory of similar structures can be applied safely only to cases where all component members vary in dimensions and in the stresses they bear according to some definite function of a characteristic dimension of the whole structure.

Aircraft do not conform to these conditions, they are never geometrically similar one to another, and the components usually grouped together as structural are composed of members whose dimensions are dictated by considerations of loading which may vary in any one of a large number of differing ways with any chosen characteristic dimension. The art of producing machines of greatly increased size without running into the snag of a prohibitive structure weight is one of dodging "similarity" in any strict sense.

It is impossible to discover from the information supplied in the paper precisely how Dr. Dornier has accomplished all the necessary dodging to make possible his 50-ton type E machine.

It is, however, obvious that the general lines followed are those already commonly adopted. The wing loading used steadily increases with size. The first three boats of the series have steadily decreasing aspect ratios. That of the fourth rises slightly—which is possibly to be accounted for by the distribution of power plant weight along the wings. (It is perhaps significant that the span of the 50-ton boat is nowhere stated.) Increasing loading and decreasing aspect ratio both lead to decrease in the span from that of the corresponding "similar" machine, and a consequent marked relative decrease in wing stresses and wing structure weight.

Load factors fall as size increases. This again leads directly to a saving in structure weight.

If it can be assumed that the weights of similar wings should vary directly with the load factor—which is nearly true in practice within the usual range of load factors—wing weights of various aircraft may reasonably be compared on the basis of the corresponding weight of similar wings of unit load factor.

For the Dornier family the weight of wing structure expressed as a percentage of loaded weight rises very markedly between boats A and B, falls greatly between B and C and then rises slowly. If these percentage figures are divided by the appropriate load factors, the figure for B is still markedly high, but those for C, D and E are steadily increasing. This increase becomes still more marked and free from the irregularity previously shown in case B if weights for "Spanten" (which includes spars and members parallel thereto) only are taken.

This indicates that in wing members of this type, whose stresses are fairly closely determined by dimensional characteristics, Dr. Dornier has not entirely dodged the consequences of large size. On the other hand, he appears very effectively to have made use of the opportunities given by increase of size to save weight on those secondary members of the wing structure whose stresses are more nearly independent of the size of the aircraft than are members such as the spars.

Generally speaking, the paper confirms the opinion that the seaplane offers much greater opportunities for the development of large-sized aircraft than can be found in land machines. Higher landing speeds may be tolerated in large seagoing aircraft than could be considered for land machines of equal size, permitting of higher wing loading. Climb and ceiling—for commercial purposes over long stages—are relatively less important at sea, and therefore the effect on induced drag of cutting the span—which mainly has its effects at low speeds—is less important than for land machines which may have to climb out of small aerodromes and cross mountain ranges. (It is again perhaps significant that Dr. Dornier does not discuss the climbing performance of type E.)

On both these counts the wing weights of a seaplane of large size can be reduced more easily than in the case of a land machine of equal weight.

Hull structure weights in the seaplane should vary in a manner even more favourable to the development of large-sized aircraft. The overall dimensions of a hull are mainly determined by the necessity of giving adequate buoyancy when on the water.

Two aircraft precisely similar except in scale will have structure weights proportional to the cube of their scales, but for equal load factors the total loaded weight must be proportional to the square of the scale. The buoyancy of "similar" hulls would thus increase much more rapidly than the loaded weight of the machines required. Therefore hull dimensions need not increase with increasing loaded weight as rapidly as must the superstructure in similar aircraft.

The hull of the flying boat therefore dodges "similarity" automatically and the designer's task is thereby simplified.

Mr. O. E. Simmonds (*contributed*): Herr Dornier has rendered an exceptional service to British aviation in laying on the table information which should settle for some long time a question which has been hotly debated during the last few years—the efficiency of the large flying boat. Against, one believes, the unanimous opinion of British flying boat designers a small minority in our aeronautical community has, from time to time, advanced "irrefutable mathematical proofs based entirely on the laws of nature" that the large flying boat must be a hopeless failure. In his present paper Herr Dornier has enabled one to abolish extrapolation and to share with him the firmer basis of actual figures on large machines.

With regard to the technical aspects of the type of flying boat which Herr Dornier has done so much to develop, one's impression is that in comparison with flying boats relying on wing-tip floats for lateral stability, the boat with stabilisers is relatively inefficient in the time to take off. From the performance figures and from one's own comparative observations on the two types of boat, in each case comparing similar power loadings and wing loadings, this fact

seems to be fairly well established and if it is inherent in this method of obtaining lateral stability it must seriously impair the serviceability of the boat for open sea work. This fact is not mentioned to detract from the merits of these stabilisers in other directions, but it would be very interesting to know if Herr Dornier agrees with one on this point. Possibly in the super Wal some improvement has been effected, but if the time to take off is still on the high side, this seems a point on which a concentration of energy may yield valuable results. In this same connection Herr Dornier appears scarcely fair to the metallurgist in heaping on him all the onus for the inability of flying boats to take off in heavy seas without risk. There are many pilots who will state that the modern boat with wing-tip floats will take off whenever the weather conditions are fit for actual flying, but in designs where the stabiliser is used this dictum certainly needs considerable qualification.

It should be remembered in passing that there is yet another method of obtaining lateral stability in flying boats—by means of twin hulls—and it is to be hoped that one may ere long have the pleasure of hearing a member of the firm of Savoia which, if the exploits of the Marchese de Pinedo are any criterion, has achieved a notable success with this type.

Mr. J. D. North (*contributed*): One of the most important points in Herr Dornier's lecture is his conclusion that an aeroplane of approximately 50 tons gross weight is able to attain a higher percentage of disposable load than in the case of small machines, and he supports this statement with statistics relating to four actual aeroplanes (A, B, C, D) and one in the process of design E. Some difficulty has been found in dealing with his statistics in the form in which they are given, and they have been re-arranged as per the attached table and converted to English units. In this form their significance is more obvious to the eye of the aeronautical engineer in this country. A figure for the span of machine E has not been given, but on the assumption that the aspect ratio will be of the same order as that of machine D, it has been assumed E's span is 150 ft.

To commence with, owing to the very low span^2/weight ratio and the very high surface loading of these machines, they cannot be compared with other aeroplanes in such a way that weight ratios have the same significance as size ratios; in fact, from the point of view of structural theory, span is a more definite and important dimension when considering relative sizes than weight.

It becomes more obvious if the case of a smaller machine of about 45 ft. span is examined. Such an aeroplane loaded up to a gross weight of 10,000 lbs. would be similar to aeroplane E, and from an examination of the statistics relating to aeroplanes which have been constructed by Boulton and Paul, Ltd., one would expect to be able to construct such a machine with a load factor of 4 for a structure weight of 12 per cent. Considering that the structure includes a certain proportion of weight from parts not subject to the ordinary scale laws, this is consistent with the 33.4 per cent. structure weight for aeroplane E, and the machine would be expected to have a higher relative disposable load for the same performance. Would such an aeroplane be practicable? As a land machine it would probably require a special aerodrome, since the stalling speed would be in the neighbourhood of 90 m.p.h., while on the other hand, if it were constructed as a flying boat, as in the case of Herr Dornier's machine, the hull weight, which tends to follow an L^2 more nearly than an L^3 law, might be expected to increase the structure weight.

On the one hand it is to be remembered that the De Havilland aeroplanes D.H. 18 and D.H. 34 were moving in this direction from perfectly sound economic principles. An examination of the machines used by Imperial Airways to-day shows a movement on grounds of safety in the opposite direction. It

would seem that if an aeroplane of such very high loading is safe it has undoubted commercial advantages. If it is only safe when it rises from and alights on water, this may be a strong argument for operating commercial machines from that element. A machine of this class has of course a high induced drag, but if rate of climb is not of importance this does not seem a disadvantage. Important evidence bearing on the practical utility of such heavily loaded machines should be available from experience with aeroplane D, and it would be interesting to have full particulars of the services operated with this machine and the extent to which they are able to carry on in adverse weather conditions. Some aeroplanes with exceptionally heavy loading have been tried in this country, but reports on their behaviour, particularly with the engine stopped, have not been favourable. Does no additional danger arise from the high rate of descent inevitable with this class of aeroplane?

Generally speaking, one would infer from the tables that aeroplane E is structurally more efficient than aeroplane D. The ratio of the wing weight to the structure weight is about what one would expect, but the reduction in the percentage spar weight is rather surprising, and is presumably to be explained by the more efficient (*i.e.*, permissibly more elaborate by reason of increase of size) design and the relieving loads from the multiple engine system.

It has already been indicated by another German designer that a naturally heavy system of structural design may be made possible by the use of very heavy wing loading. Herr Dornier has made it clear that the exceptionally large aeroplane may be made similarly practicable. The case of the smaller aeroplane with an efficient structure, on the lines suggested at the beginning, seems worthy of exploration. Certain difficulties present themselves from the point of view of providing cabin accommodation on an aeroplane of 45 ft. span with a disposable load of 7,000 lbs., but the possibilities of such an aeroplane seem worth investigating.

Type.	H.P.	Surface sq. ft.	Span feet.	All up Weight.	Structure Weight.	Structure Weight as % of all up wt.	Wing Loading lbs. sq. ft.	Power Unit lbs.	Power Unit as % of all up Weight.	W/H.P. in lbs. per B.H.P.
A	80	166	32	1477	623	42.0	8.9	427	29.0	18.4
B	450	570	57.5	6304	2544	40.0	11.0	1083	17.2	14.0
C	900	1020	74	13290	5007	37.6	13.0	2195	16.5	14.7
D	2000	1540	94	31070	10580	34.0	20.0	5182	16.6	15.5
E	6000	5000	(150?)	113600	37880	33.4	22.7	15750	13.8	18.9

	Tare Weight.	Tare Weight Plus Crew.	Disposable Load.
A	1125	1301	176
B	3831	4184	2120
C	7470	7998	5292
D	16250	16950	14120
E	54970	56610	56990

	"V" max.	"V" cruising.
A	85 m.p.h.	68 m.p.h.
B	100 ,,	87 ,,
C	119 ,,	99 ,,
D	137 ,,	105 ,,
E	149 ,,	115 ,,

	Structure.						Wing Wt. as % of Structure Weight.
	Wing Weight.	Tail Unit.	Control.	Hull.	Nacelles.	Paint Work.	
A	238.5	25.12	63.7	435.2	38.5	22.0	38.3
B	1180.0	148.8	108.0	917.0	102.5	88.1	46.4
C	1692.0	314.5	154.3	2219.0	451.8	176.3	33.7
D	4185.0	499.2	402.2	4459.0	726.4	308.5	39.5
E	16480.0	1606.0	710.7	15950.0	2363.0	771.3	43.5

	Spar Weight.	Spar Weight as % of wing wt.
A	60.8	25.0
B	427.5	36.3
C	776.7	45.85
D	1804.0	43.15
E	6870.0	41.75

Major A. R. Low (*communicated*): There was a large accumulation of evidence that aeroplanes which exceeded the current limit of practicable size developed the same sort of family troubles, notably:—Mere failure to carry a reasonable load; sagging under their own weight; and from the structural decrepitude of cut factors of safety; instability in the air from excessive reduction of the length of the body to same weight, or mere inability to leave the ground.

He much feared that Herr Dornier would find out in a very expensive way what a rational analysis of structural stresses would have indicated at insignificant cost.

If he were wrong he would be the first to congratulate the lecturer on a notable achievement.

He regretted that he had been unable to attend the lecture, but as he had translated the paper, he was familiar with the argument.

He felt that the actual performance of existing large flying boats, particularly the Rohrbach Rosco and the Dornier super Wal, did not justify the daring extrapolation to a flying boat of roughly 25 tons tare weight. The claim that it would carry in addition 25 tons of disposable load (a total of 50 tons) seemed to him fantastic. If these claims were indeed established by tests, in the near future, he should have to re-cast completely his present views, based on the accumulated experience of 20 years of aeronautical development. In particular he would have to believe that all designers in the past had been shockingly incompetent in the way they had used, or failed to use, their structural materials. He was supposing that no new wonderful structural material had been discovered, nor did Herr Dornier make any such suggestion.

Dr. Dornier's Reply to the Discussion

To the question of Colonel Mervyn O'Gorman I may say that the loading per square foot of the type E is not 30 lbs., but 22.6. With this wing loading the take-off, especially with very big aeroplanes, can be guaranteed without further precaution.

To the questions of Major Buchanan I may answer that the tandem arrangement no doubt produces a certain loss of efficiency. This is compensated in my opinion by the reduced resistance obtained by leaving off one gondola, as well as a certain improvement in the efficiency of the screw.

Our researches have shown that, *e.g.*, type C, in which we have been using the tandem arrangement for ten years, is capable of holding its own with all similar planes, both at home and abroad, which employ any other motor arrangement.

Long researches on the properties of air-cooled pusher motors have not been carried out by us, but up to the present there have not been any important objections to their use. By certain modifications of the air-cooled motor the difficulties which nowadays crop up here and there will doubtless in the immediate future be resolved by the help of the motor engineer.

Difficulties in regard to the lateral stability of boats with stumps have not arisen. Perhaps the stumps tried in England were arranged in a different fashion with regard to the c.g. of the apparatus to what we do. I should be very interested to hear more of such researches in England.

Mr. Short asked me why I am so fond of steel spars. My preference for the use of steel for highly stressed and important parts is the result of extraordinarily satisfactory researches with steel conducted over many years. I will not commit myself to say that with duralumin construction equally satisfactory results will not be obtained, as I have myself used duralumin for spars.

I was very interested in the statement of Mr. Short that in England the caulking of hulls is done without packing. In this way no doubt much weight can be spared, and I will not omit to try whether our floats and boats cannot be made watertight without our usual thickening.

Mr. Fairey speaks of the complications which he thinks must ensue with the employment of twelve motors. I have tried to reduce the complication in this way:—Two motors are combined in each gondola into a double motor. I believe that there is little difference between a single motor with 18 cylinders and a double motor with 2×9 cylinders. The double motor has the property that if one cylinder breaks down, not 18 cylinders but only nine are affected. The control of the revolutions, oil pressure and temperature is not done by the pilot, but by a mechanic from a "kiosk." By special indicators the pilot can see which motors are running and what maximum power he has available. Starting and regulation of the motors is also done from the kiosk. The pilot has thus the control of many motors through a single gas handle. Further, he can at need vary the gas and shut off particular motors.

The question of the employment of a few large motors has been considered by me, but I came to the conclusion that at the present stage of motor construction it is better to use small units, for I do not know of a motor of over 500 h.p. that is sufficiently trustworthy.

I was very interested in the remarks of Mr. A. V. Roe. Our researches show that there are fewer defects with rear propellers than forward propellers. We have used the pusher propeller much more than the tractor. We have reduced the disadvantages to a minimum, and the defects which remain are just as likely to occur with a tractor. I might remark that up to the present we have not had an accident due to breakage of a pusher screw. With regard to Mr. Roe's question whether I expect to reach 30 lbs. per square foot surface, I would say that I think that such a loading for the wing area used by us up to the present, which runs up to 480 square metres, is rather too large. With the type E the wing loading will be about 22.5 lbs. per square foot. Researches to discover the influence of the hull on the plane undertaken by us were carried out by measurements in the wind channel. The boat was fixed as an "Attrappe" and measurements made on the plane. The influence was found to be not unimportant.

I am grateful to Mr. North for his remarks. I can appreciate that the different units in my paper must make the data difficult for most of you to understand, but I hope that you will soon adopt the metric system as used by us.

To the questions of Major Bumpus I may answer that with the increase in size of aeroplanes the load factor can be reduced. Fig. 17 shows that the factor of safety for type E by 50 tons is equal to 4, whereas for an aeroplane of 5 tons

it is $5\frac{1}{2}$. Very careful consideration of the reduction of the factor of safety with the increase in weight has not been made in Germany. We work under regulations made by the Deutsche Versuchsanstalt fur Luftfahrt in conjunction with the German aeroplane industry.

Planes with invariable section have not been used much because the gain in weight is more than set off by the increased cost of the construction. Aerodynamic advantages over the cylindrical wing are not shown by the variable cross section.

I am very pleased that Mr. Mitchell also comes to the conclusion that with the increase in size the radius of action and usefulness of the aeroplane will be increased. One feels rather isolated in this aspiration, and is very pleased to find that this idea has gained ground abroad. We always put the fuel in the boat itself. The advantage of this arrangement is that in case of a big repair the tanks can be removed, also the fuel is kept as far as possible from the motors so that it cannot catch fire. It has not happened that the fuel has ever been damaged by sea.

As far as the question of Mr. Mitchell concerns our researches on the corrosion of duralumin in the the sea I cannot give any more information. I believe that the researches are the same in all countries and my opinion on this question is that practice has shown that boats and floats made of duralumin last about five or six years if a suitable varnishing and care is given it.

The answer to Mr. Wyn-Evans is that the boats mentioned in the paper fulfil the German regulations as regards safety. These regulations are made up by the Deutschen Versuchsanstalt fur Luftfahrt in conjunction with the industry. As far as they concern the "prescribed low factors" for flying boats, these regulations are not very definite. One starts from the "safe load" at which no permanent deformation can be produced.

The formula given by Mr. Wyn-Evans is to be corrected as follows:—

$$c = KV_L^{1.5}[(1+w^{\frac{1}{2}})/(1+w^{\frac{1}{4}}+w^{\frac{1}{2}})]$$

With this formula one gets about 15 to 20 per cent. higher values than with Mr. Wyn-Evans' formula. The factor c is not a safety factor but a stress factor (see condition factors 3 to 5). Mr. Wyn-Evans' formula applies to plates free from flexibility. We cannot use this formula for our constructions for the plates are used as membranes. Investigations on the effects of a tension on plates for which the flexibility was of the same order as the strength have been carried out in Germany by Foeppl (*Drang und Zwang*, Vol. I.).

I was very interested in Mr. Spanner's remarks. Investigations on more than 100 flying boats of type C have shown that these boats possess the normal seaworthiness. We have also shown that in a fairly rough sea these boats can be driven with safety, tugged or left at anchor for a long time. I do not know whether the type E will possess the same properties, but I think that an increase in size of the plane will increase its seaworthiness, as increasing the size is a common way of improving this factor.

The film was taken under sea condition 3 in the Baltic. No doubt the movement of the boat in which the operator stood increased the apparent roughness of the sea. I cannot accept the objection that when lying at anchor the inertia forces can produce considerable stresses on the structure. The forces at landing and taking off are much greater than those experienced in riding or lying to in a rough sea.

I was sorry that I could not show Sir Sefton Brancker the type E on his last visit to Friedrichshafen as the boat was not "at home." I hope to be able to show this "mysterious" boat to Sir Sefton Brancker if he will come again.

Recent research has shown that the stumps which we have used for many years require modification when the size of the plane is increased. Sir Sefton Brancker asked me to account for my preference for the monoplane. Up to the present experience has shown that the monoplane possesses advantages as regards simplicity of construction. We have used biplanes for small machines.

As regards the use of metal for planes, in our early types we always used metal skeletons covered with fabric. In the year 1917 we built the first machine with metal covering. This machine had a 185 h.p. motor. Since the war we have built a series of all-metal planes, but we have come to the conclusion that the low weight and cheapness of the fabric-covered plane is preferable. Nowadays we use both. It is very difficult to make very large planes completely in metal. For example, the type E made in metal to the same weight would only allow of a thickness of metal of 1.2 mm. which is obviously unworkable, so that one is obliged to make part of the plane of wooden beams whereas the rest, particularly the nose and tail, are covered with thin metal.

I was very interested in the remarks of Colonel Fell. In Germany low compression is used because we have come to the conclusion that the use of high compression upsets the reliability of the motors. I am not a good enough motor engineer to speak with certainty on this question, but certain firms are conducting experiments with high compression motors.

In reply to Major Rennie, the clearance of 21.2 ft. given in Table I. of type E gives the distance of the propeller disc above the water-line. Major Rennie must be mistaken when he says that in Table I. the power loading of type E is given as 18.8. The maximum of power loading is shown in Table VIII. to be the number given by Major Rennie. This is the power loading for the *maximum allowable* loading. I would point out that in type E one is concerned with motors supported from underneath for which the power loading can be carried higher than for unsupported motors. As far as the difference between types D and E in aerodynamic qualities are concerned, I would say that very careful experiments in Göttingen form the basis of our loading factors. The polar for type E is very different from that for type D. The arrangement for motors in type E is better, for about 40 per cent of the surfaces will be influenced in a satisfactory manner by the propeller slipstream.

From Major Rennie's table one sees that when 40 per cent. of the wing is in the slipstream the wing loading should be 17.4 lbs. per sq. foot. Of course, you cannot use these values without modification on type E. It is interesting to note from Major Rennie's data that the conditions common in England lead to a speed of about 55 miles = about 100 kilos. per hour. In my opinion this speed cannot be exceeded with small planes, but with large planes I think it would be impossible to have such low starting speeds.

Mr. Walker thinks that no general conclusion can be drawn from the data which I have given on the increase of the disposable load with increasing size. I realise that it is impossible to extrapolate from results which apply to a given range without criticism.

Captain Sayers thinks that one must not speak of a too narrow similarity between the flying boats of my family. I think though, although one cannot speak of a similarity in the geometrical and mechanical sense, the collected figures possess some interest. My object was to give you data on a family of flying boats which, critically and logically examined, would be of value for your own work. I think from the approbation which the gentlemen who joined in the discussion showed, that I have fulfilled this object.

Mr. Simmonds remarks that the boat with stumps is inferior to the boat with side floats in regard to lateral stability. I think that as long as the boat has reached a certain speed of about 30 knots, the lateral stability in both cases

can be controlled with the help of "interlacing." At this speed a boat with side floats can no doubt be brought more readily to a given measure of lateral stability than is possible with stumps; but the question is, what measure of lateral stability is to be taken, as up to the present no boat with stumps has been upset through too small a lateral stability? I think, however, that, taken with the advantages which the stumps possess, as Sir Sefton Brancker has pointed out in the discussion, this system has a future. My ideal would be a self-stable boat without stumps and floats, but we should only reach this with weights of about 90 tons.

I myself have, unfortunately, no experience with boats with side floats, and do not know whether, as Mr. Simmonds says, they are safer to take off in rough weather. If this is so, is it not perhaps because your British flying boats have very small wing loading and power loading? The seaworthiness of an aeroplane is very closely connected with these factors. I would like to know whether damage by sea to the side floats, which are attached to the planes, occurs in a rough sea.

I agree with Mr. North that one should choose a higher wing loading for seaplanes than land planes. I think that increase of size of the seaplane is more feasible and will make more progress than with the land plane. The highest wing loading that we have used for the latter up to the present is about 12 lbs. per sq. foot, whereas in type D seaplane 18 lbs. per sq. foot is practicable. As regards the performance of type D in practice, I may say that similar planes are in the service of the Luft Hansa at Strecken in the Baltic, and also in the service of the Italian Air Line, Societa Anonima di Navigazione Aerea (Sana) in the Mediterranean, for the line between Genoa and Barcelona and between Ostra and Tripoli. Mr. North mentions researches with heavily loaded planes in England in which reports on their behaviour with the engine stopped had been unfavourable. As far as I know, this loading was greater than in my flying boats, especially as one ought to consider not the absolute wing loading, but the relation of this to the size of the boat. I can answer Major Low's remarks briefly. It is customary for us to investigate the aerodynamic and static factors for a new plane before the actual construction, and I think this is the case elsewhere. If one incorrectly applies the rules of statics the difference between the design and the result can amount to a complete failure. It has never happened in my work that the weight of a newly constructed plane differed so much from previous calculations that the plane did not fulfil the project as designed. I am sorry that I cannot give a figure of the type E for the Press, but I would like to point out that as far as relative dimensions—distance of the outer structures from the c.g. (body length); dimensions of the rudder and stabilising surfaces; as well as in all other parts—the machine is *absolutely normal*. Nothing has been risked in reaching the desired effect. Whether the performance predicted in the paper will be reached must be left to the future.

Finally, I should like to thank all those gentlemen who took part in the discussion for their interest, and also to apologise if I have not completely answered the questions transmitted to me later. Long journeys and pressure of business have not allowed me sufficient time.

(*Dr. Dornier's reply was translated from the original German by Dr. Richardson.*—Ed.)

SECONDARY STRESSES IN AIRSHIP HULL STRUCTURES

PART III.—AN EXPERIMENTAL INVESTIGATION

BY J. F. BAKER, M.A., M.SC.

In Part I. of this paper* the theoretical stress analysis was given for a hexagonal braced tubular structure, supported at one end and subjected at the other to a system of longitudinal forces, giving no resultant load and no resultant couple. This tube had no bracing members in the planes of the bulkheads.

The analysis shows that the loads in certain types of members increase from bay to bay as they leave the neighbourhood of the applied system. This is due to the fact that the shear, in a direction parallel to the axis of the tube, across any panel (such as (1-2) Fig. 1) has the same value for every bay in the structure; and if the applied system is such that the loads in each pair of bracing wires in the panel are of opposite sign, then if any readjustment of load occurs from bay to bay, the load in one wire must increase and in the other decrease from bay to bay.

In an actual airship structure the bulkheads are so constructed, by the introduction of radial bracing or by other means, that it is possible for shear to be transmitted from one panel to another. In such a case the loads in the bracing wires would, in all probability, take up a different distribution. It was felt desirable, therefore, to analyse the stresses in a structure which, by the introduction of some bracing system to the bulkheads, would represent more closely the essential features of an actual airship hull.

The introduction of a bracing system in each bulkhead so complicated the structure that the method of stressing employed in Part I. of this paper proved impracticable. Orthodox methods of airship stressing are inapplicable when the external load system gives no resultant action, and as no other workable analytical treatment could be found, the only alternative was to make use of an experimental method. So little, however, is known of the effect of a no resultant load system on a structure of this type that it seemed probable that even the limited information given by an experimental investigation on an actual structure would be of value.

Experiments were therefore carried out on a structure with different types of bulkhead bracing and, for the verification of the analytical results of Part I., on a structure with no bulkhead bracing.

Structure and Strain Gauges

The structure and the method used for measuring the strains in the members have been fully described elsewhere.† A short summary only is given here.

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* The Journal of the Royal Aeronautical Society, December, 1927.

† R.M. 948. "An experimental investigation into the properties of certain framed structures having redundant bracing members."—A. J. S. Pippard and J. F. Baker.

Phil. Mag., July, 1925. "On an experimental verification of Castigliano's Principle of Least Work and of a theorem relating to the torsion of a tubular framework."—A. J. S. Pippard and J. F. Baker.

Journal R.Ae.S., May, 1926. "The experimental analysis of frameworks with special reference to the problems of airship design."—A. J. S. Pippard.

The structure and the details of a joint are shown in Fig. 1. The length of each bay was 30in., the side of the hexagon was 25in., giving the length of a bracing wire as 39.0in. All longitudinals and transverse members were steel tubes $\frac{7}{8}$in. O.D. and 22 gauge (0.028in. thick), with the exception of longitudinal $A_4B_4C_4 \ldots$ which was made of $\frac{7}{8}$in. diameter solid steel bar. The bracing wires in the panels were 4 B.A. swaged rods, and in all experiments, except those in which a bracing wire in each panel was removed, these wires were initially tensioned so as to be operative in compression. Provision was made for introducing bracing of any size into the bulkheads. The longitudinal and transverse members were connected to the joints by short dowels (Fig. 1). This gave a very close approximation to pin-joints.

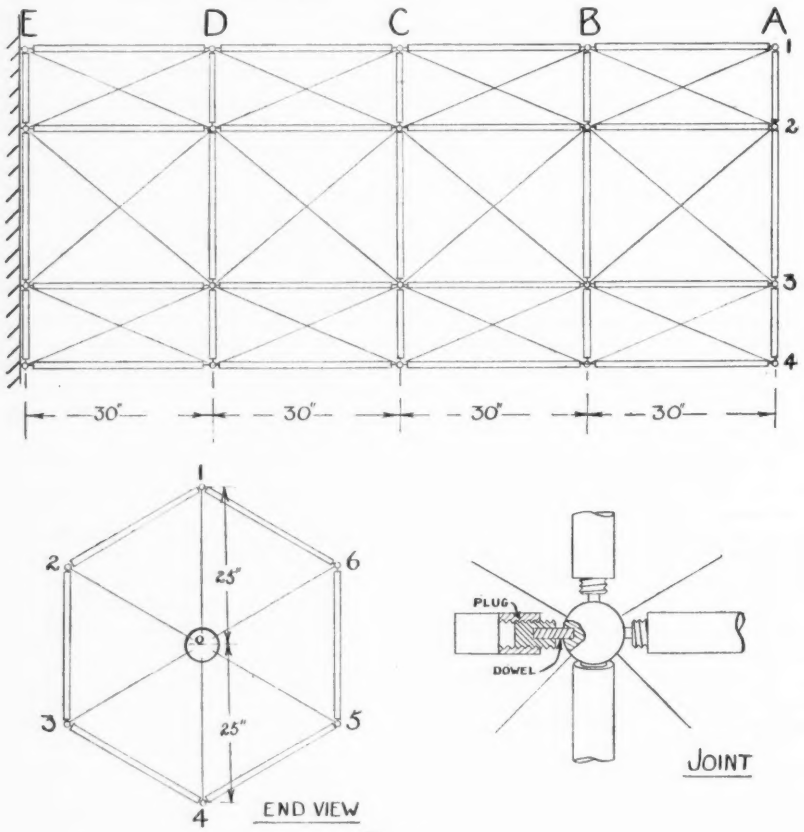


FIG. 1.

The loads in the members were measured by means of strain gauges. On each member an aluminium gauge, 15in. long, was fixed; clamped to the member at one end by a knife edge and set screw and carrying at its free end a pane of glass with a scratch on its underside, at right angles to the axis of the member. The scratch was viewed through a micrometer microscope, and its distance from a scratch made on the member could be measured. The alteration of the distance

between the scratches, under load, gave a measure of the strain. Calibration showed that an alteration in distance between the scratches measured by one division of the micrometer head represented a load of 1.02 lbs. in a 4 B.A. swaged rod, and of 7.84 lbs. in a $\frac{3}{8}$in. O.D. 22g. steel tube.

Method of Applying the Load System

In all experiments, one end of the structure was connected by dowels at the joints to a heavy plate bolted to a wall; the free end was loaded.

The load system applied was to give no resultant load and no resultant couple. This was arranged by means of the system of levers shown in Figs. 2 and 3.

The vertical lever was made up of two 4in. × 3in. × 54in. red pine beams, bolted together and separated at top and bottom, and at a point 14½in. from the bottom, by distance pieces 1in. wide. Steel bearing plates, ¼in. thick, were screwed to the outside of the lever near the top and bottom, their centres being 50in. apart. A bearing plate was also placed on the inside of the lever, its centre being 12½in. above the centre of the lower plate.

The horizontal lever consisted of a 4in. × 3in. × 46in. beam. Bearing plates were fixed at the ends on the inside, and one at the centre of the beam on the outside; the centre of this latter plate was recessed with a conical hole ¼in. diameter.

Turnbuckles were fixed by means of bolts and lugs to joints A_1 and A_4. Each passed through the middle of the vertical lever and a bar through the eye of the turnbuckle bore against the outside plate.

A ½in. diameter steel ball placed in the recess in the centre plate of the horizontal lever separated the two levers. The plates on the inside of the horizontal lever bore against ½in. diameter steel balls which rested in recesses in the centres of joints A_3 and A_5. For purposes of adjustment, a plumb-bob was suspended inside the vertical lever.

When the turnbuckles were tensioned, they applied longitudinal loads at A_1 and A_4, in inverse ratio to the distances between the turnbuckles and the fulcrum, that is, the ball separating the two levers, and an equilibrating force, equal to the sum of these loads, at the fulcrum. This equilibrating force in its turn applied longitudinal loads at A_3 and A_5 through the horizontal lever. The external loads thus applied were $+P$ and $+3P$ at joints A_1 and A_4 respectively and $-2P$ at joints A_3 and A_5.

In the earlier experiments the levers were self-centring. The turnbuckles could be accurately adjusted in line with the longitudinals A_1B_1 and A_4B_4. The balls at joints A_3 and A_5 were fixed in their correct position, since they rested in recesses at the centres of the joints. The only adjustment possible, therefore, was at the ball separating the levers. If this ball did not lie on the line of centres of balls A_3 and A_5, then the horizontal lever turned about its long axis; if it did not lie on the line joining the centres of the turnbuckles, then the vertical lever turned about its long axis. The adjustment could be made by moving the horizontal lever bodily, since the recess in its outside plate was sufficient to carry with it the centre ball, leaving those at A_3 and A_5 unmoved.

After the apparatus had been in use for some time the horizontal lever became sluggish, due to slight indentations being formed in the end plates, and it was possible to apply the load with this lever out of its true position. This was discovered when the readings showed a fairly large and equal resultant moment in each bay. To remedy this, the ¼in. plates at the ends of the horizontal lever were replaced by ½in. plates in which a horizontal "V" groove had been cut, lying in the same plane as the long axis of the lever and the recess in the centre

plate. On erecting, this groove engaged with the balls at joints A_3 and A_5; if the lever was levelled so that its axis remained in the same horizontal plane as A_3 and A_5, then the ball separating the levers took up its correct position. This method was entirely satisfactory.

On the application of a comparatively small load, the horizontal lever remained in place unsupported. This was taken as the initial or zero load. The vertical lever was supported by a jack carrying a cup and a 1in. diam. steel ball on which the foot of the lever rested, thus ensuring that no horizontal load of appreciable magnitude was applied by friction.

This method of loading through turnbuckles gave no direct measure of the external load applied at each joint, but, where necessary, it could be arrived at indirectly by measuring the load in a longitudinal in tension.

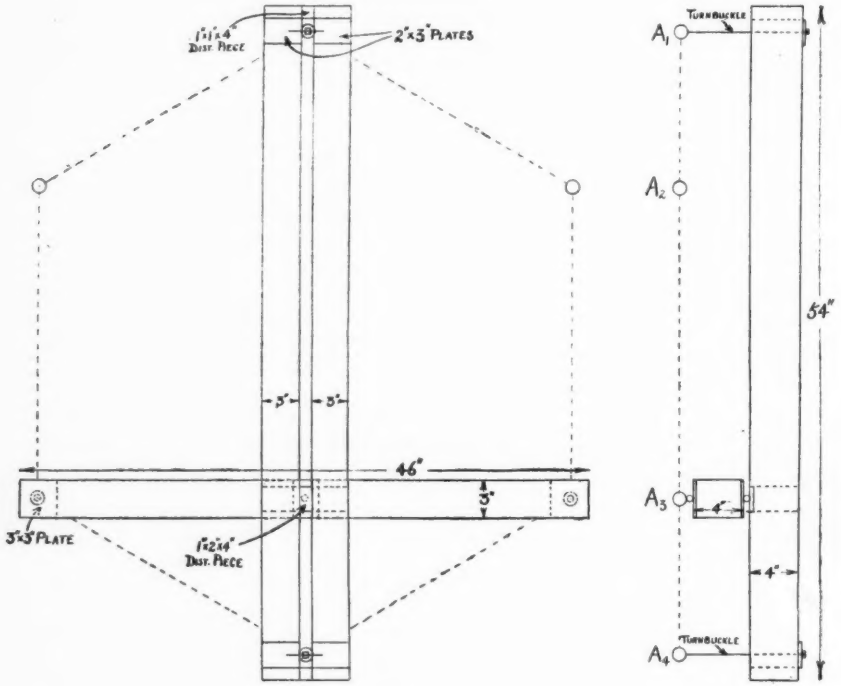


FIG. 2.

Conduct of Experiments

Previous experience with this structure had shown that the readings obtained on any tubular member under compression were unreliable. By taking readings on two points diametrically opposite on a tubular member in tension satisfactory readings could be obtained, but due to the comparatively large cross section of the tubes, these readings had not the same order of accuracy as those given by the wires. No readings therefore were taken on any tube, with the exception of A_1B_1, which, in one experiment, was measured to obtain an estimate of the actual external loads. These being known, it was possible to

write down the loads in all the longitudinal members from considerations of equilibrium at the joints.

The applied load system was symmetrical about the axis A_1A_4; it was thus only necessary to take readings on the wires of one side of the structure. Check readings were taken from time to time on the corresponding members of the other side, and very good agreement was obtained.

The standard load applied was twelve half turns of the top turnbuckle in excess of the initial or zero load. This was applied for each member separately, that is to say, the zero and loaded readings were taken on one wire without moving the microscope. This procedure was adopted instead of the more obvious method of taking the zero reading on every member, then applying the external loads and taking all the final readings, because, though it added very considerably to the time taken in the investigation, it gave much greater accuracy. This added accuracy was due to the fact that the scratches had to be illuminated by a small lamp carried on the object glass end of the microscope. The scratches on the member appeared as bright spots and any slight alteration in the position of the lamp was sufficient to change their position appreciably. By applying the load for each member, the microscope, and therefore the lamp, could be left in the same position until all the readings for that member had been completed.

Notation and Units

The notation used can be seen from Fig. 1. The loaded bulkhead is called in each case A; the fixed end, therefore, being C, D or E when the structure is two, three or four bays long.

The joints in each bulkhead are numbered from 1 to 6 as shown, and a joint is defined by the letter of the bulkhead in which it lies and its number, as B_3. A member is defined by the joints which it connects, as A_1B_2.

The convention of sign is positive for a tension and negative for a compression.

A strain measured by one division of the micrometer head represented, in the 4 B.A. swaged rods, a load of 1.02 lbs. This unit, called a "micrometer unit," has been adopted in the tables of experimental results.

Correction of Errors

Table 3, Column 1, gives the loads in the bracing wires of bay AB, in micrometer units, for the first experiment.

The external loads at the bulkhead A are $+P$, $-2P$, $+3P$, $-2P$, applied at joints A_1, A_3, A_4 and A_5. The loads (in lbs.) in the members of the bay AB will then be

A_1B_1	$P-37.6$	A_1B_2	$+24.5$
A_2B_2	-0.8	A_2B_1	-5.1
A_3B_3	$-2P+73.6$	A_2B_3	$+6.1$
A_4B_4	$3P-95.6$	A_3B_2	-44.9
		A_3B_4	-51.0
		A_4B_3	$+62.2$

These loads give an out of balance moment on bulkhead B of amount 29 lb. ft.

If a separate bay, as XY, Fig. 4, is considered, in the bracing wires of which there are loads a, b, c, d, e, f lbs., then the out of balance moment M on the bulkhead will be $2(a-b+2c-2d+e-f)\times 30/39\times 25/24$ lb. ft.

If these loads are considered to be the corrections required to give equilibrium to the bay AB, then M must equal -29 lb. ft. The values of a, b, c,

etc., to give this moment could be chosen in innumerable ways. If the lack of balance is assumed to be due entirely to errors of observation then, since the method of measurement is likely to give an equal error at every reading, irrespective of the magnitude, and since there is no bias for one particular direction, a, b, c, etc., should be made equal in magnitude and the signs so chosen, that each correction is applied to diminish the whole error in moment. These corrections are given below:—

	Reading.	Correction.	Corrected Reading.
A_1B_2	+24	−2.25	+21.75
A_2B_1	− 5	+2.25	− 2.75
A_2B_3	+ 6	−2.25	+ 3.75
A_3B_2	−44	+2.25	−41.75
A_3B_4	−50	−2.25	−52.25
A_4B_3	+61	+2.25	+63.25

The out of balance moment is in every case so small that the character of the load distribution would not be changed whatever intelligent method of distributing the error was chosen. It was decided that the method already given penalised too severely the smaller loads, since the out of balance moment would not be due entirely to errors of observation, but also to errors in the application of the external load system. A fairer method would be to make each correction proportional to the measured load, each correction being so applied as to diminish the whole error in moment. The vertical shear across a bay is automatically corrected by this method.

On this assumption the corrections for bay AB are:—

	Reading.	Correction.	Corrected Reading.
A_1B_2	+24	−1.8	+22.2
A_2B_1	− 5	+0.4	− 4.6
A_2B_3	+ 6	−0.4	+ 5.6
A_3B_2	−44	+3.3	−40.7
A_3B_4	−50	−3.7	−53.7
A_4B_3	+61	+4.6	+65.6

This method has been used for correcting all experimental results, but the actual readings are in every case given so that they may be weighed on their own merits.

Verification of Analytical Results

In order to determine how far the results obtained by analysis in Part I. could be detected in practice, experiments were carried out on structures, the properties of which corresponded as closely as possible to those already stressed.

The structures tested were two, three and four bays long. In every case one end bulkhead of the structure was kept plane by attaching the joints in it to a rigid wall plate; the other end bulkhead, to which the standard load system was applied, was braced with radial members; there were no bracing members in the planes of the other bulkheads. These were the assumptions adopted in the theoretical investigation, except that there the radial bracing was assumed to be inextensible. In the case of the structure two bays long, the loaded bulkhead was braced with 4 B.A. swaged rods; in the other two structures, these were replaced by bars $\frac{5}{8}$in. in diameter, which were virtually inextensible compared with the other members.

The experimental results are given in Tables 1, 2 and 3.

Experiment 1

Structure two bays long. Bulkhead "A" braced with 4 B.A. swaged rods. Bulkhead "B" unbraced. Standard load.

TABLE 1.

	Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+24	+22.2	A_1B_2	B_1C_2	+22	+20.5	B_1C_2
A_2B_1	− 5	− 4.6	A_2B_1	B_2C_1	− 8	− 7.5	B_2C_1
A_2B_3	+ 6	+ 5.6	A_2B_3	B_2C_3	+13	+12.1	B_2C_3
A_3B_2	−44	−40.7	A_3B_2	B_3C_2	−36	−33.5	B_3C_2
A_3B_4	−50	−53.7	A_3B_4	B_3C_4	−45	−48.2	B_3C_4
A_4B_3	+61	+65.6	A_4B_3	B_4C_3	+66	+70.7	B_4C_3

Experiment 2

Structure three bays long. Bulkhead "A" braced with $\frac{5}{8}$in. bars. Bulkheads "B" and "C" unbraced. Standard load.

TABLE 2.

	Reading.	Corrected Load.			Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+28	+28	A_1B_2	B_1C_2	+23	+24.1	B_1C_2	C_1D_2	+20	+20.9	C_1D_2
A_2B_1	− 7	− 7	A_2B_1	B_2C_1	−10	−10.5	B_2C_1	C_2D_1	−13	−13.6	C_2D_1
A_2B_3	+ 1	+ 1	A_2B_3	B_2C_3	+ 8	+ 8.4	B_2C_3	C_2D_3	+15	+15.7	C_2D_3
A_3B_2	−41	−41	A_3B_2	B_3C_2	−31	−32.4	B_3C_2	C_3D_2	−23	−24.1	C_3D_2
A_3B_4	−62	−62	A_3B_4	B_3C_4	−52	−49.6	B_3C_4	C_3D_4	−63	−60.0	C_3D_4
A_4B_3	+58	+58	A_4B_3	B_4C_3	+70	+66.7	B_4C_3	C_4D_3	+57	+54.3	C_4D_3

Experiment 3

Structure four bays long. Bulkhead "A" braced with $\frac{5}{8}$in. bars. Bulkheads "B," "C" and "D" unbraced. Standard load.

TABLE 3.

	Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+26	+26	A_1B_2	B_1C_2	+21	+21.4	B_1C_2
A_2B_1	− 6	− 6	A_2B_1	B_2C_1	−12	−12.2	B_2C_1
A_2B_3	+ 4	+ 4	A_2B_3	B_2C_3	+ 8	+ 8.1	B_2C_3
A_3B_2	−36	−36	A_3B_2	B_3C_2	−30	−30.5	B_3C_2
A_3B_4	−41	−41	A_3B_4	B_3C_4	−45	−44.2	B_3C_4
A_4B_3	+71	+71	A_4B_3	B_4C_3	+68	+66.8	B_4C_3

	Reading.	Corrected Load.			Reading.	Corrected Load.	
C_1D_2	+17	+17.1	C_1D_2	D_1E_2	+15	+14.9	D_1E_2
C_2D_1	−15	−15.1	C_2D_1	D_2E_1	−17	−16.9	D_2E_1
C_2D_3	+13	+13.1	C_2D_3	D_2E_3	+17	+16.9	D_2E_3
C_3D_2	−27	−27.2	C_3D_2	D_3E_2	−24	−23.8	D_3E_2
C_3D_4	−49	−48.6	C_3D_4	D_3E_4	−65	−65.5	D_3E_4
C_4D_3	+65	+64.5	C_4D_3	D_4E_3	+47	+47.4	D_4E_3

Another experiment was carried out in this series, in which the structure was three bays long and the conditions were identical with those of Experiment 2, except that members A_2B_1, B_2C_1, C_2D_1, and the corresponding members on the opposite side of the structure were removed. The results are given in Table 4.

Experiment 4

Structure three bays long. Bulkhead " A " braced with $\frac{5}{8}$in. bars. Bulkheads " B " and " C " unbraced. Members A_2B_1, B_2C_1, C_2D_1, etc., removed. Standard load.

TABLE 4.

Micrometer units.

A_1B_2	+35	B_1C_2	+33	C_1D_2	+34

Loads in other members indistinguishable, within limits of experimental observation, from those of Experiment 2.

It would be impossible, due to the appreciable length of the tubular members taken up by dowels and plugs, to represent the properties of these members with sufficient accuracy in the Ω form and therefore no attempt has been made to stress the actual structures by the formulæ of Part I. Such stressing is unnecessary, as the point of interest is not the individual magnitudes of the loads, but the variation of the load distribution from bay to bay. The agreement in distribution between theory and practice can be examined if the theoretical and actual structures were of the same type. This was arranged to be the case. In the actual structures the approximate values of the properties of their members were

$$1/\Omega_L = 1\ ;\ 1/\Omega_l = 7.8 \text{ and } 1/\Omega_d = 139$$

and the ratio of length of diagonal bracing wire to longitudinal was 39/30.

The theoretical structures stressed in Part I. were composed of members with the following properties:—

$$1/\Omega_L = 1,\ 1/\Omega_l = 10,\ 1/\Omega_d = 200,$$

and the ratio of length of diagonal bracing wire to longitudinal equalled 4/3.

The theoretical loads (in tension coefficient notation) in such structures two bays and four bays long, due to the standard load system, are given in Tables 5 and 6 below, which are taken from Tables 1 and 2, Part I.

TABLE 5.

Structure two bays long.

A_1B_2	$+0.0479\,p$	B_1C_2	$+0.0447\,p$
A_2B_1	$-0.0024\,p$	B_2C_1	$-0.0056\,p$
A_2B_3	$-0.0026\,p$	B_2C_3	$+0.0038\,p$
A_3B_2	$-0.0854\,p$	B_3C_2	$-0.0790\,p$
A_3B_4	$-0.1451\,p$	B_3C_4	$-0.1391\,p$
A_4B_3	$+0.0708\,p$	B_4C_3	$+0.0768\,p$

TABLE 6.

Structure four bays long.

A_1B_2	$+0.0609\,p$	B_1C_2	$+0.0567\,p$	C_1D_2	$+0.0525\,p$	D_1E_2	$+0.0483\,p$
A_2B_1	$-0.0163\,p$	B_2C_1	$-0.0205\,p$	C_2D_1	$-0.0247\,p$	D_2E_1	$-0.0289\,p$
A_2B_3	$+0.0059\,p$	B_2C_3	$+0.0143\,p$	C_2D_3	$+0.0227\,p$	D_2E_3	$+0.0311\,p$
A_3B_2	$-0.0920\,p$	B_3C_2	$-0.0836\,p$	C_3D_2	$-0.0752\,p$	D_3E_2	$-0.0668\,p$
A_3B_4	$-0.1729\,p$	B_3C_4	$-0.1655\,p$	C_3D_4	$-0.1581\,p$	D_3E_4	$-0.1507\,p$
A_4B_3	$+0.1001\,p$	B_4C_3	$+0.1075\,p$	C_4D_3	$+0.1149\,p$	D_4E_3	$+0.1223\,p$

The points of interest in the theoretical distribution are:—

(1) That the shear across any panel is constant (it can be seen from Table 6 that the shear across the panel 1—2 has the constant value $0.0772\,p \times \frac{3}{4}$).

(2) That in a wire of a given type the load either increases or decreases by a constant amount from bay to bay (it can be seen from Table 6 that in the wire 1—2 there is a constant decrease of 0.0042 p).

The uniformity of shear distribution found in practice can be seen from Tables 2 and 3 for the three and four bay structures respectively. From Table 2 it can be seen that the shear across the panel 1—2 has the value 35 K, 34.6 K and 34.5 K* in bays AB, BC and CD. The full results are given in Tables 7 and 8, which are compiled from Tables 2 and 3.

TABLE 7.

Panel	AB	BC	CD
1—2	35 K	34.6 K	34.5 K
2—3	42 K	40.8 K	39.8 K
3—4	120 K	116.3 K	114.3 K

TABLE 8.

Panel	AB	BC	CD	DE
1—2	32 K	33.6 K	32.2 K	31.8 K
2—3	40 K	38.6 K	40.3 K	40.7 K
3—4	112 K	111.0 K	113.1 K	112.9 K

With one exception, that of panel 3—4 (Table 7), the shear across any panel is constant within the limits of accuracy of observation (± 2 K).

In all three experiments the loads in the bracing wires either decrease or increase from bay to bay. From Table 2 these increments or decrements are seen to be, for the wires 1—2, 3.9 from bay AB to bay BC, and 3.2 from bay BC to bay CD; the corresponding changes in the wires 2—1 being 3.5 and 3.1. The full results are given in Tables 9 and 10, which are compiled from Tables 2 and 3.

TABLE 9.

	Increment or decrement from	
Wire	AB—BC	BC—CD
1—2	3.9	3.2
2—1	3.5	3.1
2—3	7.4	7.3
3—2	8.6	8.3
3—4	12.4	[−10.4]
4—3	8.7	[−12.4]

TABLE 10.

	Increment or decrement from		
Wire	AB—BC	BC—CD	CD—DE
1—2	4.6	4.3	2.2
2—1	6.2	2.9	1.8
2—3	4.1	5.0	3.8
3—2	5.5	3.3	3.4
3—4	3.2	4.4	[16.9]
4—3	4.3	2.3	[7.1]

Ignoring, for the moment, the figures in brackets [ ], the increments or decrements for any type of wire with the exception of 2—1 (Table 10) are approximately uniform from bay to bay within the limits of accuracy of observation (± 1).

* K is the ratio 30/39 obtained due to the resolution of the loads in a longitudinal direction.

The irregularity of the figures in brackets is due to the loads in the wires of panel 3—4 in the last bay of each structure.

For this panel in Experiment 1 the distribution is normal, as it is for the first two bays of Experiment 2, and for the first three of Experiment 3. For the last bay in these two latter experiments, however, the distribution can be seen to be irregular.

It was discovered, while carrying out Experiment 2, that in the bulkhead member C_3C_4 the solder holding an end plug (Fig. 1) in the tube had failed. This allowed the plug to move into the tube and made the member incapable,

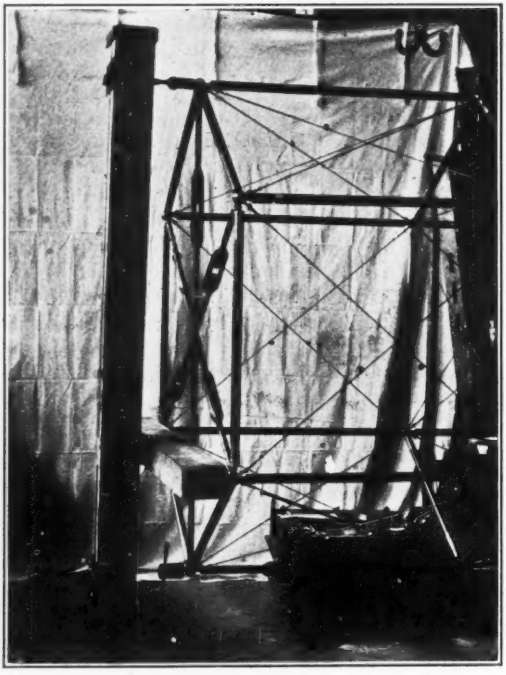


FIG. 3.

or only partly capable, of taking load. The distribution in C_3D_4 and C_4D_3 (Table 2) will be found to be compatible with this state of affairs. An attempt was made to repair this member, without dismantling the whole structure, by driving a pin through the tube and plug. Though the plug was prevented from moving further into the tube, the pin does not appear to have proved a perfect connection, since Table 3 shows that in the four-bay case the loads in the members (which are now D_3E_4 and D_4E_3) are still affected. The regularity of distribution in the members of the first three bays of panel 3—4 (Table 3) and of the other panels, bears out the theoretical results, and makes it appear that the discrepancy in the members D_3E_4 and D_4E_3 was due only to a fault in the structure.

When there is only one wire operative in a panel, it must transmit the whole of the shear across that panel, and its load therefore remains constant from bay to bay. This is shown in Experiment 4, where it also appears that there

is no redistribution of shear when one wire is removed from each of the upper panels. Since the removal of a member in a redundant structure affects the behaviour of the structure as a whole, some redistribution of shear is likely to occur, though it is too small to be detected in the case tested.

Structures with Bracing Systems in all Bulkheads

No great headway can be made, by analytical methods, in investigating the state of stress in a tubular structure which has some form of bracing in the plane of every bulkhead.

The most that has been found possible has been the stressing of a structure two bays long, the bracing in the bulkheads consisting of inextensible radial members connecting each joint to a central plate.

The methods and nomenclature used are those of Part I., and the structure is the same as the one there stressed, with the addition of bracing members in bulkhead "B." The tension coefficients in these additional bracing members, B_1B_0, B_2B_0, etc., are called S_1, S_2 and S_4, corresponding to R_1, R_2 and R_4, the tension coefficients in the members A_1A_0, A_2A_0, etc. (Fig. 1).

The complete list of tension coefficients for the structure, under the standard external load system used in the experimental investigation, is given in Table 11.

TABLE 11.

A_1B_1 $p-2a_1$	B_1C_1 $p+2(R_1-R_2)-2b_1$
A_2B_2 $-(R_1-R_2)-a_1-a_2$	B_2C_2 $-2(R_1-R_2)+(R_4-R_1)-b_1-b_2-(S_1-S_2)$
A_3B_3 $-2p-(R_4-R_1)-a_2-a_3$	B_3C_3 $-2p-3(R_4-R_1)-(R_4-R_2)-b_2-b_3-(S_4-S_1)$
A_4B_4 $3p-2(R_1+R_2-2R_4)-2a_3$	B_4C_4 $3p-4(R_1+R_2-2R_4)-2b_3-2(S_1+S_2-2S_4)$
A_1B_2 a_1	B_1C_2 b_1
A_2B_1 $(R_1-R_2)+a_1$	B_2C_1 $(R_1-R_2)+b_1+(S_1-S_2)$
A_2B_3 a_2	B_2C_3 b_2
A_3B_2 $(R_4-R_1)+a_2$	B_3C_2 $(R_4-R_1)+b_2+(S_4-S_1)$
A_3B_4 a_3	B_3C_4 b_3
A_4B_3 $(R_1+R_2-2R_4)+a_3$	B_4C_3 $(R_1+R_2-2R_4)+b_3+(S_1+S_2-2S_4)$
A_1A_0 R_1	B_1B_0 S_1
A_2A_0 R_2	B_2B_0 S_2
A_3A_0 $R_1+R_2-R_4$	B_3B_0 $S_1+S_2-S_4$
A_4A_0 R_4	B_4B_0 S_4

The ten strain energy equations are:—

$$(R_1-R_4)[10/\Omega_L+22/\Omega_1+6/\Omega_d]+(R_2-R_4)[10/\Omega_L-6/\Omega_1]+a_1[1/\Omega_1+1/\Omega_d]-a_2[1/\Omega_d]+a_3[2/\Omega_L-1/\Omega_1+1/\Omega_d]+b_1[1/\Omega_1+1/\Omega_d]-b_2[1/\Omega_d]+b_3[4/\Omega_L-3/\Omega_1+1/\Omega_d]+(S_1-S_4)[4/\Omega_L+6/\Omega_1+3/\Omega_d]+(S_2-S_4)[4/\Omega_L-3/\Omega_1]+p[-9/\Omega_L-7/\Omega_1]=0 \quad . \quad . \quad (1)$$

$$(R_1-R_4)[10/\Omega_L-6/\Omega_1]+(R_2-R_4)[10/\Omega_L+8/\Omega_1+4/\Omega_d]+a_1[-1/\Omega_1-1/\Omega_d]-a_2[1/\Omega_1]+a_3[2/\Omega_L+1/\Omega_d]+b_1[-1/\Omega_d]-b_2[3/\Omega_1]+b_3[4/\Omega_L-1/\Omega_1+1/\Omega_d]+(S_1-S_4)[4/\Omega_L-1/\Omega_1]+(S_2-S_4)[4/\Omega_1+2/\Omega_1+2/\Omega_d]+p[-3/\Omega_1-9/\Omega_L]=0 \quad . \quad (2)$$

$$(R_1-R_4)[1/\Omega_1+1/\Omega_d]+(R_2-R_4)[-1/\Omega_1-1/\Omega_d]-p[1/\Omega_1]+a_1[3/\Omega_1+2/\Omega_d]+a_2[1/\Omega_1]=0 \quad . \quad . \quad . \quad (3)$$

$$(R_1-R_4)[1/\Omega_d]+(R_2-R_4)[1/\Omega_1]-p[2/\Omega_1]-a_1[1/\Omega_1]-2a_2[1/\Omega_1+1/\Omega_d]-a_3[1\Omega_1]=0 \quad . \quad . \quad (4)$$

$$(R_1-R_4)\,[2/\Omega_L-1/\Omega_1+1/\Omega_d]+(R_2-R_4)\,[2/\Omega_L+1/\Omega_d]$$
$$+p\,[2/\Omega_1-3/\Omega_L]+a_2\,[1/\Omega_1]+a_3\,[2/\Omega_L+1/\Omega_1+2/\Omega_d]=0 \quad . \quad (5)$$

$$(R_1-R_4)\,[1/\Omega_1+1/\Omega_d]+(R_2-R_4)\,[-1/\Omega_d]-p\,[1/\Omega_1]+b_1\,[3/\Omega_1+2/\Omega_d]$$
$$+b_2\,[1/\Omega_1]+(S_1-S_4)\,[1/\Omega_1+1/\Omega_d]+(S_2-S_4)\,[-1/\Omega_1-1/\Omega_d]=0 \quad (6)$$

$$(R_1-R_4)\,[1/\Omega_d]+(R_2-R_4)\,[3/\Omega_1]-p\,[2/\Omega_1]-b_1\,[1/\Omega_1]-2b_2\,[1/\Omega_1+1/\Omega_d]$$
$$-b_3\,[1/\Omega_1]+(S_1-S_4)\,[1/\Omega_d]+(S_2-S_4)\,[1/\Omega_1]=0 \quad . \quad . \quad (7)$$

$$(R_1-R_4)\,[4/\Omega_L-3/\Omega_1+1/\Omega_d]+(R_2-R_4)\,[4/\Omega_L-1/\Omega_1+1/\Omega_d]$$
$$+p\,[2/\Omega_1-3/\Omega_L]+b_2\,[1/\Omega_1]+b_3\,[2/\Omega_L+1/\Omega_1+2/\Omega_d]$$
$$+(S_1-S_4)\,[2/\Omega_L-1/\Omega_1+1/\Omega_d]+(S_2-S_4)\,[2/\Omega_L+1\Omega_d]=0 \quad . \quad (8)$$

$$(R_1-R_4)\,[4/\Omega_L+6\Omega_1+3/\Omega_d]+(R_2-R_4)\,[4/\Omega_L-1/\Omega_1]+b_1\,[1/\Omega_1+1/\Omega_d]$$
$$-b_2\,[1/\Omega_d]+b_3\,[2/\Omega_L-1/\Omega_1+1/\Omega_d]+p\,[-3/\Omega_L-2/\Omega_1]$$
$$+(S_1-S_4)\,[2/\Omega_L+2/\Omega_1+3/\Omega_d]+(S_2-S_4)\,[2/\Omega_L-1/\Omega_1]=0 \quad . \quad (9)$$

$$(R_1-R_4)\,[4/\Omega_L-3/\Omega_1]+(R_2-R_4)\,[4/\Omega_L+2/\Omega_1+2/\Omega_d]+b_1\,[-1/\Omega_1-1/\Omega_d]$$
$$+b_2\,[-1/\Omega_1]+b_3\,[2/\Omega_L+1/\Omega_d]+p\,[-3/\Omega_L]$$
$$+(S_1-S_4)\,[2/\Omega_L-1/\Omega_1]+(S_2-S_4)\,[2/\Omega_L+1/\Omega_1+2/\Omega_d]=0 \quad . \quad (10)$$

When these equations are solved ($1/\Omega_L=1$; $1/\Omega_1=10$; $1/\Omega_d=200$) they give

$(R_1-R_4)=+0.1190\,p$	$a_1=+0.0662\,p$	$b_1=+0.0315\,p$
$(R_2-R_4)=+0.1990\,p$	$a_2=+0.0168\,p$	$b_2=-0.0187\,p$
$(S_1-S_4)=-0.0823\,p$	$a_3=-0.1947\,p$	$b_3=-0.0791\,p$
$(S_2-S_4)=-0.1374\,p$		

and the resulting tension coefficients from Table 11 are given in Table 12.

TABLE 12.

A_1B_1 $+0.8676\,p$	B_1C_1 $+0.7770\,p$
A_2B_2 $-0.0030\,p$	B_2C_2 $-0.0269\,p$
A_3B_3 $-1.7031\,p$	B_3C_3 $-1.4285\,p$
A_4B_4 $+2.7534\,p$	B_4C_4 $+2.3256\,p$
A_1B_2 $+0.0662\,p$	B_1C_2 $+0.0315\,p$
A_2B_1 $-0.0138\,p$	B_2C_1 $+0.0066\,p$
A_2B_3 $+0.0168\,p$	B_2C_3 $-0.0187\,p$
A_3B_2 $-0.1022\,p$	B_3C_2 $-0.0554\,p$
A_3B_4 $-0.1947\,p$	B_3C_4 $-0.0791\,p$
A_4B_3 $+0.1233\,p$	B_4C_3 $+0.0192\,p$

These figures should be compared with Table 5, which is the corresponding case without bracing in the bulkhead "B." It will be seen that the bracing in bulkhead "B" adds stiffness to the first bay, and so causes larger loads in the counter bracing wires A_1B_2, A_2B_1, etc., but that it also makes the corresponding loads decrease (with the exception of B_2C_1) in the second bay.

The change of shear from bay AB to bay BC is (in tension coefficient notation):—

In panel 1—2 from $+0.0800\,p$ to $+0.0249\,p$ or a decrease to 31.2%.
In panel 2—3 from $+0.1190\,p$ to $+0.0367\,p$ or a decrease to 32.5%.
In panel 3—4 from $-0.3180\,p$ to $-0.0983\,p$ or a decrease to 30.9%.

Experimental Investigation

Since it was impossible to push the analysis further, experiments were carried out on three structures, two, three and four bays long, which were identical with those used in Experiments 1, 2 and 3, except that radial bracing systems were introduced into all the bulkheads.

In the first series of experiments the bracing system consisted of six radial members, made of 4 B.A. swaged rods, connecting the joints to a central wiring plate.

The results are given in Tables 13, 14 and 15.

Experiment 5

Structure two bays long. Bulkheads "A" and "B" braced with 4 B.A. rods running to central wiring plate. Standard load.

TABLE 13.

	Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+30	+28.5	A_1B_2	B_1C_2	+14	+11.6	B_1C_2
A_2B_1	− 8	− 7.6	A_2B_1	B_2C_1	− 5	− 4.1	B_2C_1
A_2B_3	+11	+10.5	A_2B_3	B_2C_3	+ 8	+ 6.6	B_2C_3
A_3B_2	−48	−45.6	A_3B_2	B_3C_2	−31	−25.5	B_3C_2
A_3B_4	−60	−63.0	A_3B_4	B_3C_4	−23	−27.0	B_3C_4
A_4B_3	+81	+85.0	A_4B_3	B_4C_3	+45	+52.9	B_4C_3

It will be seen, on comparing these results with Table 1 which gives the loads for the corresponding structure without bracing in bulkhead "B," that the loads in the wires of bay AB are, in every case, greater, due to the introduction of the bracing, while the loads in all wires of bay BC show a decrease. This bears out the results obtained by analysis.

Comparative figures showing change of shear from bay AB to bay BC are:—

In panel 1—2 from +36.1 to +15.7 or a decrease to 43.5%.
In panel 2—3 from +56.1 to +32.1 or a decrease to 57.2%.
In panel 3—4 from −148.0 to −79.9 or a decrease to 54.0%.

These decreases are less than those found by analysis, which is not an unexpected result, as the bracing assumed in the analytical case was inextensible. The difference, however, is not so very marked when it is considered that the actual radial bracing of Experiment 5 was of the same cross-sectional area as the bracing in the panels, and therefore very far from being inextensible.

Experiment 6

Structure three bays long. Bulkhead "A" braced with $\frac{5}{8}$in. bars. Bulkheads "B" and "C" braced with 4 B.A. rods running to central wiring plate. Standard load.

TABLE 14.

	Reading.	Corrected Load.			Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+27	+27.4	A_1B_2	B_1C_2	+12	+12	B_1C_2	C_1D_2	+ 9	+ 9.1	C_1D_2
A_2B_1	−18	−18.3	A_2B_1	B_2C_1	−10	−10	B_2C_1	C_2D_1	− 4	− 4.0	C_2D_1
A_2B_3	+16	+16.3	A_2B_3	B_2C_3	+ 4	+ 4	B_2C_3	C_2D_3	+ 2	+ 2.0	C_2D_3
A_3B_2	−38	−38.6	A_3B_2	B_3C_2	−33	−33	B_3C_2	C_3D_2	−10	−10.1	C_3D_2
A_3B_4	−79	−77.7	A_3B_4	B_3C_4	−59	−59	B_3C_4	C_3D_4	−23	−22.7	C_3D_4
A_4B_3	+79	+77.7	A_4B_3	B_4C_3	+37	+37	B_4C_3	C_4D_3	+15	+14.8	C_4D_3

As in the previous experiment, the loads in the wires of bay AB (with the exception of A_1B_2) are greater than the corresponding loads in the structures without bulkhead bracing (Table 2).

The loads in all the wires show a decrease from bay AB to bay BC, and from bay BC to bay CD. No "pattern" is obvious in these decreases, wire 1—2 decreases in bay BC to 43.8 per cent. of its value in bay AB, and in bay CD to 75.0 per cent. of its value in bay BC. Corresponding percentages are, for wire 2—1 54.6 and 40.0 per cent., and for wire 2—3 24.5 and 50 per cent.

For panel 1—2 the shear decreases in bay BC to 48.1 per cent. of its value in bay AB, and in bay CD to 59.6 per cent. of its value in bay BC. Corresponding percentages for the other panels are, panel 2—3 67.4 and 32.7 per cent., panel 3—4 61.6 and 39.1 per cent.

In order to estimate the value of the external loads, the load in A_1B_1 was measured in this experiment. Its value was +321.4 lbs., which makes the external load, called previously P, +364.4 lbs. or 357.3 micrometer units. By resolution at the joints, the loads in all the members may be written down, they are given in Table 15 in micrometer units.

TABLE 15.

A_1B_1	+315.1	B_1C_1	+268.5	C_1D_1	+239.1
A_2B_2	+ 1.5	B_2C_2	− 2.5	C_2D_2	− 17.1
A_3B_3	−626.5	B_3C_3	−483.5	C_3D_3	−448.5
A_4B_4	+955.0	B_4C_4	+779.0	C_4D_4	+666.0
A_1B_2	+ 27.4	B_1C_2	+ 12.0	C_1D_2	+ 9.1
A_2B_1	− 18.3	B_2C_1	− 10.0	C_2D_1	− 4.0
A_2B_3	+ 16.3	B_2C_3	+ 4.0	C_2D_3	+ 2.0
A_3B_2	− 38.6	B_3C_2	− 33.0	C_3D_2	− 10.1
A_3B_4	− 77.7	B_3C_4	− 59.0	C_3D_4	− 22.7
A_4B_3	+ 77.7	B_4C_3	+ 37.0	C_4D_3	+ 14.8

These results, which agree very well with those obtained by analysis for the two-bay case (Table 12), show how the loads decrease in all the members with the exception of A_2B_2, B_2C_2 and C_2D_2, the longitudinal to which no external load is applied.

Experiment 7

Structure four bays long. Bulkhead "A" braced with $\frac{3}{8}$in. bars. Bulkheads "B" and "C" braced with 4 B.A. rods running to central wiring plate. Standard load.

TABLE 16.

	Reading.	Corrected Load.			Reading.	Corrected Load.	
A_1B_2	+19	+19.2	A_1B_2	B_1C_2	+22	+20.7	B_1C_2
A_2B_1	−40	−40.4	A_2B_1	B_2C_1	−21	−19.8	B_2C_1
A_2B_3	+27	+27.3	A_2B_3	B_2C_3	+11	+10.4	B_2C_3
A_3B_2	−43	−43.4	A_3B_2	B_3C_2	−30	−28.2	B_3C_2
A_3B_4	−89	−88.1	A_3B_4	B_3C_4	−50	−53.0	B_3C_4
A_4B_3	+114	+112.9	A_4B_3	B_1C_3	+61	+64.6	B_4C_3
C_1D_2	+10	+ 8.8	C_1D_2	D_1E_2	+ 8	+ 8.0	D_1E_2
C_2D_1	−13	−11.4	C_2D_1	D_2E_1	− 9	− 9.0	D_2E_1
C_2D_3	+ 3	+ 2.6	C_2D_3	D_2E_3	+ 7	+ 7.0	D_2E_3
C_3D_2	−10	− 8.8	C_3D_2	D_3E_2	+10	+10.0	D_3E_2
C_3D_4	−20	−22.5	C_3D_4	D_3E_4	− 7	− 7.0	D_3E_4
C_4D_3	+18	+20.3	C_4D_3	D_4E_3	+ 4	+ 4.0	D_4E_3

In general, the distribution in this case is similar to that already found in the other experiments. The loads in bay AB are all greater, with the exception (as in Experiment 6) of A_1B_2, than the corresponding loads in the structure without bulkhead bracing (Table 3). The loads in the wires decrease from bay to bay at much the same rate as in Experiment 6, except that B_1C_2 shows an increase of 7.8 per cent. on A_1B_2, but as C_1D_2 decreases again to 42 per cent. of B_1C_2, this may very possibly be due to an error of observation. The load in wire 3—2 changes from a compression in the third bay to a tension in the fourth, which has not occurred before, though a similar change over is indicated in the analysis (Table 12).

The percentages to which the shear decreases, given in the same form as in the previous experiments, are:—

In panel 1—2: 68%, 50% and 84%.
In panel 2—3: 54.6%, 29.6% and −26.3%.
In panel 3—4: 58.5%, 36.4% and 25.8%.

The values of the loads in bay DE show how small is the shear across the panels by the time the fourth bay is reached.

So far the loads in the longitudinals have not been considered, except in Table 15, since no readings were taken on them, but they are important and must be examined.

Effect on Longitudinal Loads

The effect on the loads in the longitudinals, of the introduction of bulkhead bracing, can be seen for a structure two bays long by a comparison of the analytical results contained in Table 1, Part I., the case of no bracing in bulkhead "B," and Table 12, the case of inextensible bracing in bulkhead "B."

These results are arranged for purposes of comparison in Table 17.

TABLE 17.

(Results obtained by analysis.)

	Unbraced Bulkheads.	Radially Braced Bulkheads.
A_1B_1	$+0.9042\,p$	$+0.8676\,p$
A_2B_2	$+0.0050\,p$	$-0.0030\,p$
A_3B_3	$-1.7695\,p$	$-1.7031\,p$
A_4B_4	$+2.8584\,p$	$+2.7534\,p$
B_1C_1	$+0.8100\,p$	$+0.7770\,p$
B_2C_2	$-0.0307\,p$	$-0.0269\,p$
B_3C_3	$-1.4832\,p$	$-1.4285\,p$
B_4C_4	$+2.4146\,p$	$+2.3256\,p$

It will be seen that in every case the loads are less when the bulkhead B is braced than when it is unbraced. The corresponding results obtained by experiment may be deduced from Tables 1 and 13, they are given in Table 18.

TABLE 18.

(Results obtained by experiment.)

	Unbraced Bulkheads.	Radially Braced Bulkheads.
A_1B_1	$P_1-44.4\,K$	$P_2-57\,K$
A_2B_2	$-K$	$-2.9\,K$
A_3B_3	$-2P_1+94.4\,K$	$-2P_2+108.6\,K$
A_4B_4	$3P_1-131.2\,K$	$3P_2-170\,K$
B_1C_1	$P_1-94.6\,K$	$P_2-95.4\,K$
B_2C_2	$-24.1\,K$	$-23.5\,K$
B_3C_3	$-2P_1+247.3\,K$	$-2P_2+256.6\,K$
B_4C_4	$3P_1-380\,K$	$3P_2-401.8\,K$

The actual values of P_1 and P_2 were not obtained. It will be seen, from the method of applying the external loads, that though the same number of turns was given to the turnbuckle for each experiment, the magnitudes of the loads would be altered if there was any change in the relative stiffness of the

structure and loading levers. The addition of bulkhead bracing would alter the stiffness of the structure, but as far as could be determined by taking readings on A_1B_1 it made no appreciable difference to the external loads. P_2 would therefore be equal to P_1, and if this is made so in Table 18, the experimental results are found to correspond, with the exception of A_2B_2, with those of analysis.

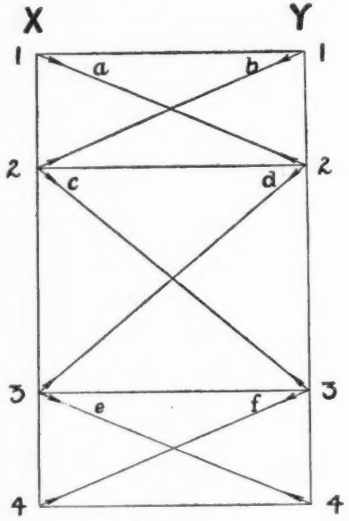


FIG. 4.

A rather different distribution is found when the number of bays is increased, thought it is not incompatible with the results for two bays.

Table 19 gives the loads in the longitudinals for a structure four bays long; these are obtained from the results of experiments (Tables 3 and 16).

TABLE 19.

(Results obtained by experiment.)

	Unbraced Bulkheads.	Radially Braced Bulkheads.
A_1B_1	$P-52\ K$	$P-38.4\ K$
A_2B_2	$+2\ K$	$+13.1\ K$
A_3B_3	$-2P+77\ K$	$-2P+131.5\ K$
A_4B_4	$3P-142\ K$	$3P-225.8\ K$
B_1C_1	$P-106.8\ K$	$P-160.6\ K$
B_2C_2	$-3.9\ K$	$-1.7\ K$
B_3C_3	$-2P+226.7\ K$	$-2P+352.9\ K$
B_4C_4	$3P-357.6\ K$	$3P-531.2\ K$
C_1D_1	$P-165.4\ K$	$P-217.8\ K$
C_2D_2	$-11.0\ K$	$-0.4\ K$
C_3D_3	$-2P+377.4\ K$	$-2P+459.2\ K$
C_4D_4	$3P-575.0\ K$	$3P-677.8\ K$
D_1E_1	$P-225.4\ K$	$P-256.6\ K$
D_2E_2	$-21.1\ K$	$+1.6\ K$
D_3E_3	$-2P+544.3\ K$	$-2P+479.1\ K$
D_4E_4	$3P-767\ K$	$3P-730.8\ K$

It will be seen that, in general, for the first three bays, the loads in the longitudinals are less when there is bulkhead bracing, but that in the fourth bay, the loads in D_3E_3 and D_4E_4 are less in the structure with no bulkhead bracing. The three-bay case shows the same effect, but more pronounced, the loads in the last bay being given in Table 20, which is obtained from Tables 2 and 14.

TABLE 20.

(Results obtained by experiment.)

	Unbraced Bulkheads.	Radially Braced Bulkheads.
C_1D_1	$P-181\,K$	$P-153.6\,K$
C_2D_2	$-15.3\,K$	$-22.2\,K$
C_3D_3	$-2P+403.2\,K$	$-2P+376.1\,K$
C_4D_4	$3P-581.2\,K$	$3P-532.4\,K$

When there is no bulkhead bracing the shear across a panel is the same, and therefore the loads in the longitudinals decrease by a constant amount, from bay to bay.

The introduction of bulkhead bracing appears to concentrate the shear in the first bay, and thus relieves the longitudinals more quickly, but since it also decreases the shear across the panels from bay to bay, the relief becomes less and less until in the last bay the longitudinal is left with a load in it greater than would have been the case had there been no bulkhead bracing.

The effect of the length of the structure can also be seen from these tables of longitudinal loads. The total shear up to any bay at a given distance from the applied load increases with the number of bays in the structure, and consequently the loads in the longitudinals of any bay at a constant distance from the free end of the structure decrease with increase of the number of bays.

Effect of Size of Bulkhead Bracing

For a structure two bays long, two cases have been investigated, one by analysis and the other by experiment, one in which the bulkhead bracing consisted of bars so large in cross-section as to be virtually inextensible, and the other in which it consisted of 4 B.A. swaged rods (0.0095 sq. in. cross-section). The average of the figure to which the shear in the second bay had decreased was found to be 31.5 and 51.5 per cent. respectively for the two cases. These results do not differ as much as might have been expected from the difference in the cross-sections of the bracing members, and therefore it was felt that a further investigation, in which the bracing members would be still lighter, was desirable. This was carried out on a structure three bays long in which the radial bracing members consisted of rope wire 0.051in. diameter.

Experiment 8

Structure three bays long. Bulkhead "A" braced with $\frac{5}{8}$in. bars. Bulkheads "B" and "C" braced with rope wire 0.051in. diameter running to a central wiring plate. Standard load.

TABLE 21.

	Corrected Reading.	Load.			Corrected Reading.	Load.			Corrected Reading.	Load.	
A_1B_2	+24	+24.2	A_1B_2	B_1C_2	+21	+21.6	B_1C_2	C_1D_2	+15	+15.0	C_1D_2
A_2B_1	−10	−10.1	A_2B_1	B_2C_1	− 3	− 3.1	B_2C_1	C_2D_1	− 8	− 8.0	C_2D_1
A_2B_3	+ 9	+ 9.1	A_2B_3	B_2C_3	+ 3	+ 3.1	B_2C_3	C_2D_3	+ 3	+ 3.0	C_2D_3
A_3B_2	−44	−44.3	A_3B_2	B_3C_2	−35	−36.0	B_3C_2	C_3D_2	−10	−10.0	C_3D_2
A_3B_4	−66	−65.5	A_3B_4	B_3C_4	−62	−60.2	B_3C_4	C_3D_4	−22	−22.0	C_3D_4
A_4B_3	+76	+75.5	A_4B_3	B_4C_3	+44	+42.7	B_4C_3	C_4D_3	+28	+28.0	C_4D_3

These results should be compared with Table 14, the loads for the three-bay case with 4 B.A. swaged rod bracing. Marked differences will be found in the loads in corresponding members of bay AB, though the change from bay to bay is similar, and the decrease in shear in two panels is of the same order. The percentages to which the shear decreases, for the case of bulkhead bracing of 0.0020 sq. ins. cross-section (0.051in. diam.), are:—

In panel 1—2 72.0% and 93.0%.
In panel 2—3 73.2% and 33.2%.
In panel 3—4 73.0% and 48.7%.

The corresponding figures for the case of bulkhead bracing of 0.0095 sq. ins. cross-section (0.11in. diam.), are:—

In panel 1—2 48.1% and 59.6%.
In panel 2—3 67.4% and 32.7%.
In panel 3—4 61.6% and 39.1%.

It will be seen that the shear decrease is very similar for panels 2—3 and 3—4, though considerably different for panel 1—2.

Bulkheads with Rigid Joints

The investigation, so far, has only dealt with bulkhead bracing systems consisting of radial members. The other practical method of bracing a bulkhead is to cut out all radial wires and to make the joints of the bulkhead rigid. A case of this type was investigated.

The six tubular bulkhead members, B_1B_2, B_2B_3, etc., were taken, and into each ball forming the joint between them was screwed a lug, lying along a radius and in the plane of the bulkhead. A hole was drilled in the lug, 1.38in. from the centre of the joint, to take a pin 0.153in. in diameter. These pins in adjacent lugs were joined by 4 B.A. swaged rods which were tensioned up, thus forming a stiff-jointed bulkhead, with outer ridge member a $\frac{3}{8}$in. diam. 22g. tube and inner ridge member a 4 B.A. swaged rod, their centres being 1.2in. apart. A diagram of part of a bulkhead is shown in Fig. 5.

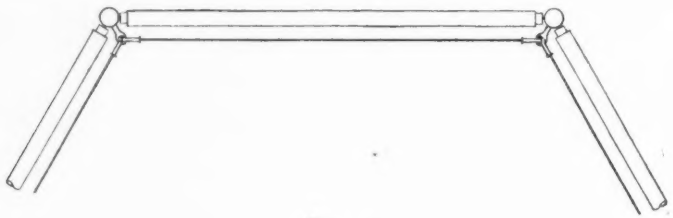


FIG. 5.

Experiment 9

Structure three bays long. Bulkhead "A" braced with $\frac{3}{8}$in. bars. Bulkheads "B" and "C" with rigid joints. Standard load.

TABLE 22.

	Corrected Reading.	Load.		Corrected Reading.	Load.		Corrected Reading.	Load.	
A_1B_2	+27	+26.4	A_1B_2	B_1C_2	+22	+23.5	B_1C_2	C_1D_2	+18	+18.5	C_1D_2
A_2B_1	− 4	− 3.9	A_2B_1	B_2C_1	−11	−11.7	B_2C_1	C_2D_1	− 9	− 9.2	C_2D_1
A_2B_3	+13	+12.7	A_2B_3	B_2C_3	+ 7	+ 7.5	B_2C_3	C_2D_3	+12	+12.3	C_2D_3
A_3B_2	−30	−29.4	A_3B_2	B_3C_2	−21	−22.4	B_3C_2	C_3D_2	−17	−17.5	C_3D_2
A_3B_4	−62	−63.3	A_3B_4	B_3C_4	−56	−52.2	B_3C_4	C_3D_4	−48	−46.6	C_3D_4
A_4B_3	+50	+51.1	A_4B_3	B_4C_3	+46	+42.9	B_4C_3	C_4D_3	+42	+40.8	C_4D_3

These results show very much less change in the loads in the wires, and therefore in the shear, from bay to bay, than do the cases with radial bracing.

The shear increases in panel 1—2 from bay AB to bay BC by 16.2 per cent., but as it decreases in bay CD to 78.6 per cent. of its value in bay BC, or a total decrease to 91.4 per cent. of its original value, some lack of perfection in the structure, or an error in observation, seems indicated. The percentages for the other panels are:—

In panel 2—3 71.0% and 100.0%.
In panel 3—4 83.0% and 92.0%.

If the results of Table 14 are compared with those of Table 22, the difference in distribution will be seen. These cases lend themselves to comparison, since the swaged rods used as inner ridge members in the last experiment were the same as those used as radial members in Experiment 6, and therefore the weights of the two bracing systems are approximately equal.

The type of bracing, therefore, seems to affect results considerably. These two cases, of radially braced and stiff-jointed bulkheads, are however very different in nature; and it was decided to choose as the next bracing system for test one which did not depart so radically from the original radial type.

The radial members, in the previous experiments, had been joined to a central wiring plate; the modification now made was to do away with this plate, so that members joined diametrically opposite joints. The bracing members thus became B_1B_4, B_2B_5 and B_3B_6 and had no connection at the point where they crossed.

Experiment 10

Structure three bays long. Bulkhead "A" braced with $\frac{3}{8}$in. bars. Bulkheads "B" and "C" braced with 0.051in. diameter rope wire joining diametrically opposite joints. Standard load.

TABLE 23.

	Reading.		Reading.		Reading.
A_1B_2	+40	B_1C_2	+27	C_1D_2	+11
A_2B_1	−27	B_2C_1	−20	C_2D_1	−15
A_2B_3	+32	B_2C_3	+37	C_2D_3	+32
A_3B_2	−60	B_3C_2	−55	C_3D_2	−53
A_3B_4	−34	B_3C_4	−31	C_3D_4	−19
A_4B_3	+35	B_4C_3	+19	C_4D_3	+16

It will be found, from these loads, that there is an almost equal moment of amount 294 lb. ft. in each bay, which must have been due to faulty adjustment of the loading levers, and therefore these results must not be compared load by load with those of Table 21 (the case of 0.051in. diameter bracing running to a central wiring plate). This applied moment, however, does not make Table 23 useless for a comparison of the effect of the bracing on the distribution from bay to bay.

It will be seen that in panels 1—2 and 3—4 the shear decreases in much the same way as it does in the structure with standard radial bracing, but in panel 2—3 it remains almost constant, having the values +92, +92 and +85. It is impossible to state how the moment was applied to bulkhead A, but it could not be due to loads at joints 2 and 3 (and 5 and 6), which might have great effect on panel 2—3 and little on the other two, since no external load could be applied at joint 2 (and 6); and, since a constant moment in each bay would cause approximately equal loads in the corresponding members in the bays, the almost unchanged state of the shear in panel 2—3 from bay to bay must be due to the type of bracing alone.

Conclusions

Although the structures tested were, from practical considerations, made as elementary as possible; and although they appear, when compared with an actual airship hull, things of little complexity, yet with the introduction of bulkhead bracing they become quite heavily redundant structures. This is fully realised when the task of interpreting the results of the experiments is approached.

The tube, which is represented by the structures used in Experiments 1—4, was kept the same throughout and various forms of bulkhead bracing were introduced into it. For the same type of bracing, a change in size altered the very form of the load distribution, since it changed the nature of the whole structure; the tube itself being unchanged. This can be seen from the experimental results. The fact that the introduction of a bracing system means many added variables makes it impossible to represent the results, in any useful form, by masses of curves; and the tables of loads, as they stand, must be studied for conclusions of a general nature to be drawn.

Experiments 1—4 verify, in a very complete way, the analytical results of Part I.

The remaining experiments show the result of introducing bulkhead bracing into the tube.

The effect of the length of the structure, or of the number of bays, can be seen for the case of radial bracing to a central wiring plate. The average percentage to which the shear across the panels decreases is 51.5 per cent. for two bays, 25.1 per cent. for three bays, and 12.6 per cent. for four bays. As the number of bays increases the bracing wires in the panels tend to be less affected, the load passing with little change along the longitudinals.

The effect of size of bracing of a given type is marked, but not extraordinarily so. When the bracing is inextensible the shear decreases in a length of two bays to 31.5 per cent. (by analysis), and when it has a cross-sectional area of 0.0095 sq. ins. to 51.5 per cent. (by experiment). In three bays, when the cross-sectional area is 0.0095 sq. ins. the shear decreases to 25.1 per cent., and to 42.2 per cent. for a cross-sectional area of 0.0020 sq. ins. The percentages given are average figures.

The type of bracing is important and, for the distribution of shear, radial bracing is shown to be the most efficient.

In order to obtain a stiff enough structure for the method of support adopted, it was necessary to have initial tension in the counter-bracing wires, making them both operative. This is unlikely to be the case in an airship under normal conditions, but a structure with only one wire operative in each panel would still be highly redundant due to the bulkhead bracing, and therefore any general deductions drawn from the results of these experiments will apply to such a structure without initial tension.

Experiments 5—10 show what an important part bulkhead bracing plays in the distribution of load, but they also show, that though the shear across the panels becomes small as the number of bays is increased, large loads still remain in the longitudinals. This applies to the condition, existing in all the experiments, that the end bulkhead is kept plane.

If an airship has its bulkheads merely braced radially, without any special provision to make them resist distortion out of their own planes, then systems of loads similar to that considered "standard" in the experiments, must be superimposed on the primary loads, if the primary loads are calculated on the assumption that plane sections remain plane. For such a ship fitted with a stiff nose-piece, which tends to keep the end section plane, the distribution due to these "standard" systems will be similar to that found in the experiments. The

loads will pass, after some readjustment in the bays near the plane of application, with little change along the longitudinals. Each bulkhead will contribute something towards these longitudinal loads, and their final magnitudes and importance will depend upon the stiffness of the nose-piece. For hulls in which the nose-piece is not stiff compared with the other bulkheads, the distribution will be entirely different and demands a separate investigation.

In the type of hull which has its bulkheads designed to resist distortion out of their own planes, the conditions are also different. Such bulkheads would be stiff-jointed, but Experiment 9 does not represent their case with any truth, since the bulkheads there had little or no rigidity out of their own planes. A bulkhead which can be considered to resist all distortion out of its own plane, when compared with the bay, washes out any no resultant system applied to it, passing no loads on to the members of the bay. The extent, therefore, to which the distribution found in these experiments applies to an airship of this construction depends entirely on the relative rigidities of the bulkheads and the bays; these could only be found from a consideration of each particular hull.

The author wishes to thank the Aeronautical Research Committee and Professor A. J. Sutton Pippard for permission to use the structure and the gauges.

He also wishes to thank Mr. A. H. Randle, of the Engineering Department, University College, Cardiff, for much assistance in erecting and repairing the structure.

REVIEWS

The Law in Relation to Aircraft

By L. A. Wingfield and R. B. Sparkes. (Longmans, 12s. 6d.)

This book fills an obvious blank in aeronautical literature by bringing within covers all the existing law, international and domestic, regarding aircraft. The first sixty-four pages are devoted to brief resumés of the appendices which constitute the remainder, and therefore much the greater part of the whole three hundred pages in the book. It is extremely convenient to have the International Air Convention as well as the British Air Navigation Act, 1920, and appendant Orders and Directions all ready to hand for reference, particularly as in the latter case the amendments made by later Directions are incorporated in the text of the originals in italic type. The authors' own work in the preliminary chapters is somewhat sketchy and might with advantage have been expanded. There is at present, and the fact is rather surprising, no case law to be quoted, which appears to show that flying men are a law-abiding race. But it would have been interesting to have, for purposes of record, one or two of the few prosecutions that have so far taken place.

It has been the practice of many great lawyers, and is often a necessary preliminary to the interpretation of a modern statute, to look at the evolution and growth of legislation on a subject, in order to arrive at an understanding of the reasons lying behind the existing law. This book would have been much improved if the authors had adopted this course, instead of treating the subject as if the Convention and Act of 1920 had sprung into being without precedents.

In the chapter on International Regulations, for instance, they write of Article I. of the Convention, declaring a State's sovereignty over its air space, as "nothing but declaratory of an already well-recognised proposition of international and municipal law." But in point of fact this principle had never until 1919 received formal international recognition, and it was specifically because what came to be known as the "continental school" of aeronautical jurists refused to admit it that many pre-war international conferences broke down without reaching agreement. Views in favour of sovereignty gradually hardened during the war, but the principle had never been universally agreed on until the Peace Conference.

In their chapter on the English law the authors similarly ignore the Air Navigation Acts, 1911 to 1919, which the Act of 1920 repealed, though it is by no means certain that they may not some day prove of more than pure historic or academic interest.

The section of the 1920 Act which is of most interest to lawyers, and most likely to prove fruitful of litigation, is Section 9, which provides that no action shall lie for trespass or nuisance "by reason only of the flight of aircraft over any property at a height above the ground, which, having regard to wind, weather, and all the circumstances of the case is reasonable. . . ." This seems to be universally interpreted in air circles, and the view appears to be adopted by Mesrs. Wingfield and Sparkes as giving aircraft owners complete immunity from any cause of action for nuisance while in flight. This view was stretched to its extreme limit by the present Director of Civil Aviation when he informed the residents round Hamble Aerodrome that they would just "have to grin and bear" the noise of the aeroplanes. There is absolutely nothing in the wording of the section to justify any such wide interpretation, and any aeroplane owner

who relies on it as a defence to an action for nuisance may find himself rudely awakened. It is impossible to conceive that the Courts would hold that under no circumstances can the noise of an aeroplane's engine give rise to a legal nuisance, and there is nothing in the section to suggest any intention of the Legislature to confer such immunity.

A new section introduced this year into the Consolidated Order under the Air Navigation Act gives the Air Ministry the appearance of power of control over such foolhardy feats as long oversea flights in single-engined land planes, which it did not previously possess. But it, unfortunately, only lays the onus of seeing that the aircraft is fit in every way " for the proposed flight " on " the person in charge." It would have been better to have given the Secretary of State power to prohibit such flights unless he were satisfied that the aircraft was fit. As it is, the section is probably useless, since if the aircraft is unfitted for its purpose the person in charge will not survive, whereas if he should by some miracle do so, sentimental public opinion would not permit of prosecution.

" The Law relating to Aircraft " is useful as giving the law in handy and accessible form. But we still await a true text-book of aerial law, taking the Act and Orders and Directions section by section and commenting on them.

The Story of a North Sea Air Station

By C. F. Snowden Gamble. Oxford University Press. 21/- net.

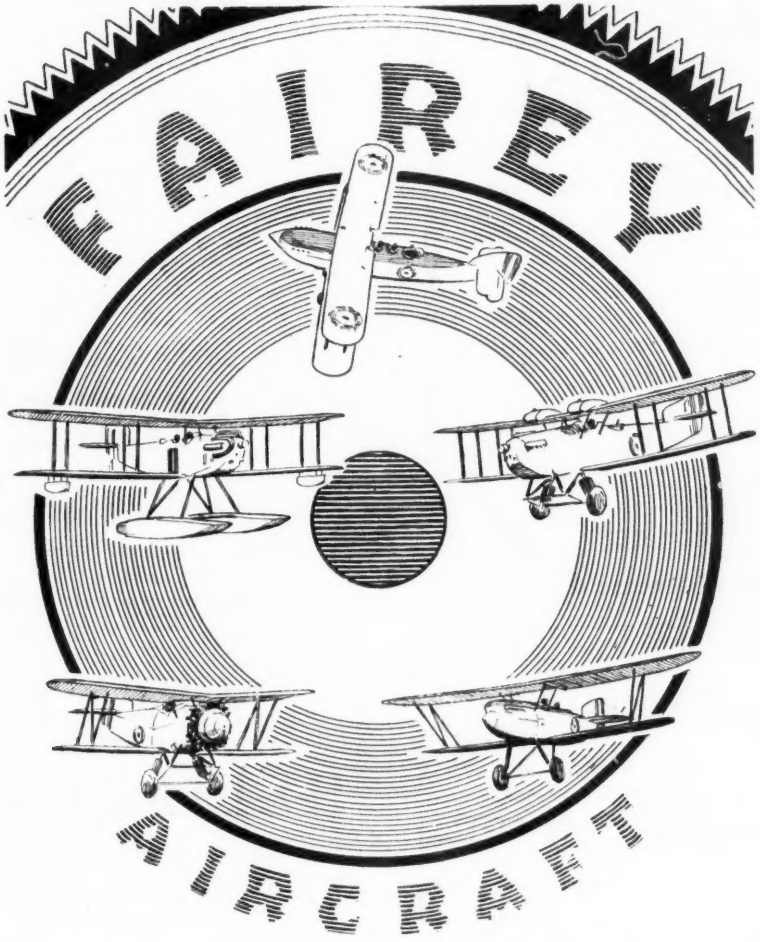
This " Account of the Early Days of the Royal Flying Corps (Naval Wing) and of the Part Played thereafter by the Air Station at Great Yarmouth and its Opponents during the War 1914-1918 "—to quote the full sub-title—arose out of the desire of those who served at Great Yarmouth Station, to possess a plain narrative record, more or less for private circulation amongst themselves, of the activities of the station during the four strenuous years of the Great War. The original intention of the author—who was himself " one of them "—to supply that desideratum, is still retained in the main title of the book. It is, however, to his credit that having seriously set to work to study available documents and to obtain first hand information from those who happily survived—both in this country and in Germany—he did not shrink from the great labour involved in the collection and painstaking collation of narratives and facts. The result, as revealed in this most interesting book, is that what was at first conceived as a simple " story," ultimately acquired many of those qualities which go to the making of a serious history. It is from that point of view—the historical rather than the technical aspect—that the present notice is written.

Though the adoption of a more or less strictly chronological method has some limitations, it has the advantage of affording the reader a series of clearly defined impressions of the progress of events. Moreover, a study of the twenty-two chapters comprised in the book equally affords a sound view of the larger issues involved. The introductory chapter consists of a brief but adequate survey of the " Early days of aviation in the Royal Navy," in which connection the wider term " aeronautics " might have been more correctly employed than aviation—despite the persistent example of those in high places who habitually fail to differentiate between the one and the other—seeing that " the earliest experiments in aeronautics undertaken by the Admiralty were made with craft lighter than air." This is followed by an account of the beginnings of the Great Yarmouth Air Station, after which the author deals with developments and events year by year, alternating the narrative with similar records of the activities of the German air stations opposed to Great Yarmouth. It is this twofold character of the narrative which constitutes one of the chief claims of the book to be regarded as a historical work, and which is destined to give it that permanent

value lacking in so many ephemeral war books. Offence and defence, in air not less than in naval operations, are intimately connected, and the importance of a right understanding of the opposing forces with which the Great Yarmouth Station had to deal, is clearly instanced in the case of the use of Zeppelin airships. In order that the early difficulties of the defence against such aircraft may be fully understood, the author has been at great pains to deal with the nature of the problem, and in so doing has given in a chapter on the "Development of the Zeppelin and the German Airship Service during the War," one of the most reliable surveys of the subject available in a brief form. Not only was he afforded much technical information by the German authorities, but he was courteously allowed to make full use of the diaries of Zeppelin commanders—diaries the extracts from which, taken in conjunction with diaries and reports of British flying officers, add greatly to the value and not less to the absorbing interest of the book. That man is indeed little to be envied—to adapt a phrase from Johnson's eloquent passage on the ruins of Iona—who does not feel a thrill on reading the story of the flying boat, the four occupants of which, after an attack on Zeppelins, alighted on the water in order to save the crew of a D.H. 4, who endured three terrible days and three nights without food and with but little water, in a damaged and leaking machine, and who were ultimately rescued in a state of dire exhaustion. Many such incidents are related in the book, and the author, in making full use of the available diaries, has been able to impart to his narration that vivid atmosphere of reality which such documents, howsoever brief and laconic, can alone afford.

On the technical side the book contains much information—compiled, as far as the present writer can judge, with care and accuracy—on the various types of flying boats, seaplanes and aeroplanes used on the station, as well as on engines, instruments, armament, wireless equipment, and so forth. The account of the Zeppelins, already referred to, is enhanced by a full list of these airships, the total number of cruises made by each, and their ultimate fate. The volume is illustrated with upwards of 30 photos—a number of which have been supplied from German sources—as well as a series of small illustrations of British aircraft, after the drawings of Mr. Leonard Bridgman. There are a few errors or misprints—in the words of a quaint apology for errata by a 17th century writer, "it is as hard to wrest thunder from the hand of Jove, as errors from the hands of the compositor"—but they are of a minor kind. As a whole the book is a careful and serious piece of work on which the author may be congratulated, and in the production of which he would doubtless allow a meed of praise to the high efficiency of the Oxford University Press.

J. E. H.



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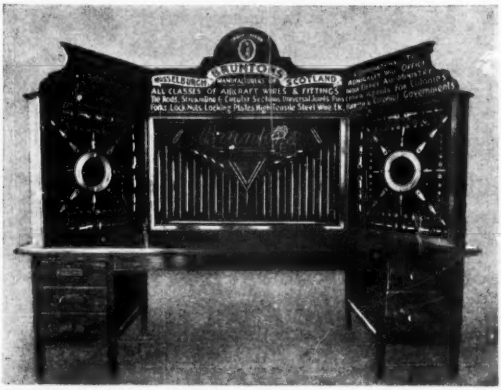

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